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Site-Related Groundwater Remedial Investigation Report

Volume 1 of 3 - Text

Ringwood Mines/Landfill Superfund Site

Ringwood, New Jersey

Revised January 2015

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Site-Related Groundwater Remedial Investigation Report

Ringwood Mines/Landfill
Superfund Site
Ringwood, New Jersey

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^{13}C	carbon-13
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AC	Area of Concern
amsl	above mean sea level
AOC	Administrative Order on Consent
ARCADIS	ARCADIS U.S., Inc.
BERA	Baseline Ecological Risk Assessment
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
BTEX	benzene, toluene, ethylbenzene, xylenes
CFC	chlorofluorocarbon
CFC-11	trichlorofluoromethane
CFC-12	dichlorodifluoromethane
CFC-113	trichlorotrifluorethane
cm^3/g	cubic centimeter(s) per gram
CM Shaft	Cannon Mine Shaft
CMP	Cannon Mine Pit
CMP RIR	Remedial Investigation Report for the Cannon Mine Pit Area
COC	constituents of concern
CO_2	carbon dioxide
COPEC	constituent of potential ecological concern
CSM	Conceptual Site Model

DIC	dissolved inorganic carbon
DNA	deoxyribonucleic acid
DO	dissolved oxygen
EBSL	ecologically based screening level
EMD	Environmental Molecular Diagnostics
EMP	Environmental Monitoring Program
fmol/kg	femtomole(s) per kilogram
Ford	Ford Motor Company
FS	Feasibility Study
ft/ft	foot per foot
GMWL	global meteoric water line
gpm	gallon(s) per minute
GWQS	Groundwater Quality Standards
GWSL	Groundwater Screening Level
IGWSCC	Impact to Groundwater Soil Cleanup Criteria
IGWDSSL	Impact to Groundwater Default Soil Screening Levels
IT^2	Isotope Tracer Technologies, Inc.
L	liter(s)
LED	light-emitting diode
LEL	Low-Effects Level
L/kg	liter(s) per kilogram
MCA	Multivariate Cluster Analysis
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mL	milliliter(s)

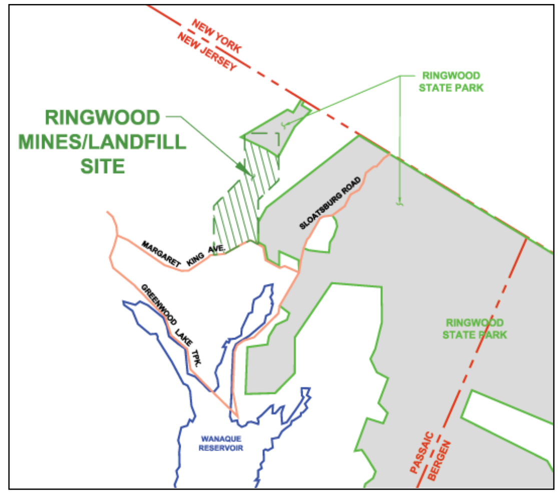
mL/g	milliliter(s) per gram
mL/min	milliliters/minute
mRNA	messenger ribonucleic acid
MTBE	methyl tertiary-butyl ether
MWL	meteoric water line
NJDEP	New Jersey Department of Environmental Protection
NPL	National Priorities List
NTU	nephelometric turbidity unit
O'Connor	O'Connor Trucking and Haulage Company
OCDA	O'Connor Disposal Area
OCDA RIR	Remedial Investigation Report for the O'Connor Disposal Area
ORP	oxidation-reduction potential
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
PDBs	passive diffusion bags
pCi/L	picocurie(s) per liter
PLFA	phospholipid fatty acids
PM Air Shaft	Peters Mine Air Shaft
pmc	percent modern carbon
pmol/kg	picomole(s) per kilogram
PMP	Peters Mine Pit
PMP RIR	Remedial Investigation Report for the Peters Mine Pit Area
Post EMP Work Plan	Post-Environmental Monitoring Program Sampling Work Plan
PSE&G	Public Service Electric and Gas Company
PVC	polyvinyl chloride

QAPP	Quality Assurance Project Plan
RDCSRS	Residential Direct Contact Soil Remediation Standards
RDCSSL	Residential Direct Contact Soil Screening Level
REEs	rare earth elements
RI	remedial investigation
RIR	Remedial Investigation Report
RNA	ribonucleic acid
ROD	Record of Decision
SEL	Severe-Effects Level
SF_6	sulfur hexafluoride
SIP	stable isotope probing
Site	Ringwood Mines/Landfill Site
SLERA	Screening-Level Ecological Risk Assessment
SR	sludge removal
SR-3	Sludge Removal Area 3
SR-6	Sludge Removal Area 6
SR-7	Sludge Removal Area 7
SR-13	Sludge Removal Area 13
SVOC	semivolatile organic compound
SWQS	Surface Water Quality Standards
TAL	Target Analyte List
TCE	trichloroethene
TCL	Target Compound List
TDS	total dissolved solids
TOC	total organic carbon

TPH	total petroleum hydrocarbons
TU	tritium unit
µg/L	microgram(s) per liter
µg/kg	microgram(s) per kilogram
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USTs	underground storage tanks
VCR	videocassette recorder
VOC	volatile organic compounds
WCC	Woodward-Clyde Consultants
ZIST^{TM}	Zone Isolation Sampling Technology

Summary Overview

Since 2005, the Ford Motor Company (Ford) has carried out additional groundwater and surface water investigation and monitoring work at the Ringwood Mines/Landfill Superfund Site located in the Borough of Ringwood, New Jersey (Site) to further characterize the quality of groundwater at the Site, enhance the understanding of groundwater and surface water movement in different areas of the Site, and assess actual or potential risks to human health or the environment. The findings from this work will be used to provide support for the selection of a final remedy for Site groundwater.

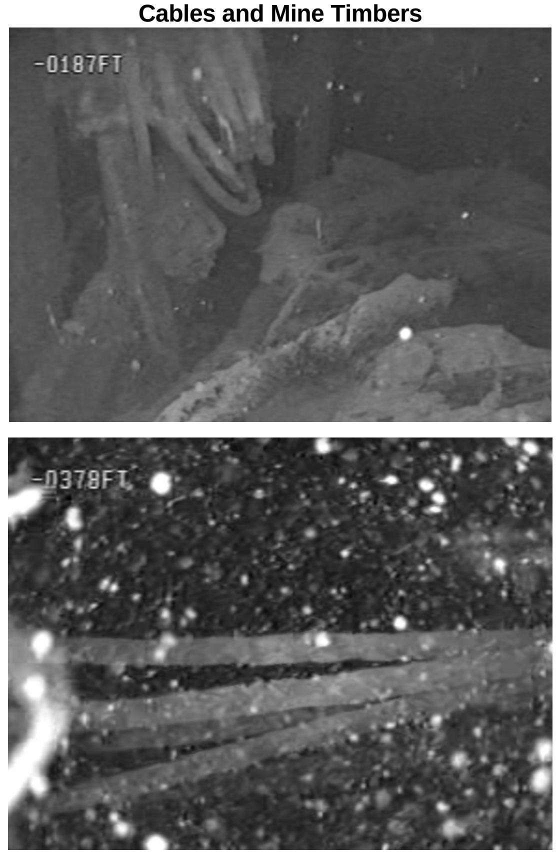


As summarized on the project timeline attached at the end of this summary, groundwater investigations of the Site have been ongoing since the first detection of paint waste and waste materials at the Site in 1984. In addition, a series of land-based investigations and paint waste removal actions have also occurred.

As described throughout this *Site-Wide Groundwater Remedial Investigation Report* (RIR), between 2005 and 2013, ARCADIS U.S, Inc. completed a supplemental and more comprehensive Site-wide investigation and continued groundwater monitoring activities to advance the science and understanding of groundwater transport. The battery of studies carried out at the Ringwood Mines/Superfund Landfill Site, considered in concert with nearly 30 years of historical data, confirm that: 1) the flow of groundwater and surface water at the Site are well understood; 2) groundwater impacts are sporadic and limited to localized landfill areas; 3) natural processes are at work lowering concentrations of benzene, lead, and arsenic – the key constituents of concern (COCs) in groundwater at the Site; and 4) Wanaque Reservoir and Ringwood Borough wells have never been impacted by Site-related COCs.

History and Background

Images from Cannon Mine Shaft Showing Abandoned Cables and Mine Timbers



The Site was an active iron mine from the mid-1700s until at least the early 1930s. The mining operations included an ore processing mill at Peters Mine with multi-level mine tunnels, incline shafts, and air shafts at the Peters Mine Pit (PMP) Area and Cannon Mine Pit (CMP) Area, with numerous smaller pits. The deepest tunnel occurs at level 17 of the Peters Mine and is 1,550 feet below ground surface. Information shared with the New Jersey Bureau of Mine Safety by the last owner indicates that the capacity of all of the mine tunnels and shafts at Peters Mine is approximately 213,000,000 gallons (when flooded). This vast network of tunnels and shafts during mining operations were kept dry via the removal of approximately 53 gallons per minute.

Although mining operations were abandoned in the 1930s, the mine was reopened and prepared for renewed mining activities in the 1940s by the Department of Defense as part of the World War II mobilization. Shafts were extended as part of these operational preparations; however, only limited mining was conducted, and the mine was again abandoned by 1951. Recent video logging of the Cannon Mine Shaft reveal abandoned mining equipment, such as cables, and elevator equipment remain (see adjacent photos).

The more recent use of portions of the Site as a disposal area led to its inclusion on the National Priorities List (NPL) in 1983. Ringwood Realty Corporation, a former subsidiary of Ford, purchased the property in 1965, and between 1967 and 1971, employed subcontractors to dispose of trash, paint waste, and other non-liquid wastes generated at the former Mahwah Assembly Plant at three locations within the Site: the PMP Area, the CMP Area, and the O'Connor Disposal Area (OCDA).

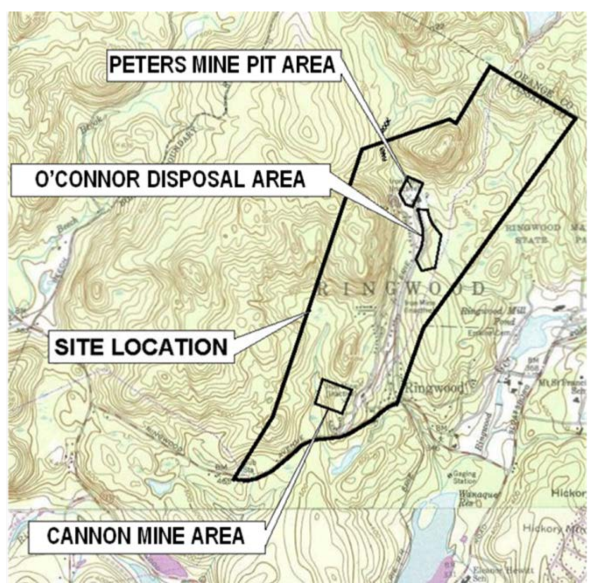
In November 1970, Ringwood Realty donated 290 acres of the Site, and by November 1971 Ringwood Realty had sold all but 145 acres of the Site, and by December 1973 Ringwood Realty no longer owned any portion of the site. Random dumping of waste materials by others occurred before, during, and after the 4-year period that Ford related wastes were disposed of at the Site. Waste materials included abandoned automobiles, white goods, tires, household trash, and general debris. In addition, junked cars have been disposed in the mine pits and other areas of the Site. Sources of COCs can be related to some or all of the associated operations.

Between 1984 and 1990, Ford completed a series of investigation and cleanup activities at the Site under the oversight of the United States Environmental Protection Agency (USEPA) to address paint waste and other waste. The work also included groundwater monitoring and sampling, the results of which showed that concentrations of Site-related constituents – specifically volatile and semivolatile organic compounds and metals – were low and not migrating off site. In 1994, USEPA removed the Site from the NPL. This action was supported by the results of a 5-year environmental groundwater monitoring program – carried out between 1990 and 1995 – which showed that Site-related constituents in groundwater were only detected sporadically, and when detected, were at generally low concentrations. Further, no constituents were found in any off-site drinking water samples, and follow-up sampling carried out at the request of USEPA in 1998, 1999, and 2000 showed that, with the exception of one groundwater monitoring well (OB-14A), lead and arsenic were below relevant health-based standards in all groundwater and surface water samples. In 2000, USEPA also confirmed that the North Jersey Water Supply District had not reported any concerns regarding the quality of the Wanaque Reservoir, a downstream public drinking water source.

After this phase of work was complete, additional paint waste deposits were discovered at the Site, prompting Ford to complete additional removal activities, and in September 2006, USEPA added the Site back onto to the NPL. Between 2004 and 2012, Ford and its contractors excavated and disposed of approximately 50,000 tons of paint waste, soil, and other waste materials from across the Site. This work, together with previous efforts, have collectively resulted in the removal and offsite disposal of all known paint waste across the surface of the Site, outside of the three known disposal areas (PMP, CMP, and OCDA), permanently eliminating potential human health or ecological exposure to these deposits. The final paint waste deposit was removed in September 2014 (identified as SR-16, ARCADIS 2013g), and solid wastes and some paint waste fragments that are consolidated within the three landfill areas-Peter's Mine Pit, Cannon Mine Pit, and O'Connor Disposal Area.

Current Phase of Work

Site Location and Areas of Concern



In 2005 while the cleanup was underway, Ford and USEPA entered into an Administrative Order on Consent (AOC) to carry out a series of supplemental investigations specifically focused on groundwater and surface water. In a subsequent AOC finalized in May 2010, USEPA divided the Site into four Areas of Concern (ACs). Three of these ACs are the primary former disposal areas – the PMP Area, the CMP Area, and the OCDA – and the fourth AC is Site-related groundwater. The AOC required Ford to prepare RIRs for each AC.

The key objectives of this RIR, which was prepared in accordance with relevant USEPA guidance and the May 2010 AOC, are to document the groundwater and surface water investigations and monitoring work performed between 2005 and 2014, develop a conceptual site model (CSM) to explain the movement of groundwater and the transport of Site-related constituents, and summarize the key findings of the work.

The focus of the efforts over the past 8 years has been to enhance the understanding of the Site-specific geology and hydrogeology. In particular, the role and influence that historical underground mine workings, the overburden (the materials at ground surface), and the shallow and deep bedrock (which sits beneath the overburden) have on groundwater and surface water flow – and ultimately the fate and transport of intermittent and low level detections of Site-related constituents.

To achieve these objectives, Ford and ARCADIS embarked on a comprehensive suite of work that included:

- Source investigation (to investigate, delineate, and characterize residual sources at the Site)
- Surface water investigation (to assess surface water quality in the on-site streams, the pond near the PMP, seeps, and locations where groundwater discharges to surface water)

- Sediment investigation (to evaluate the quality of surface sediments in on-site streams, the pond near the PMP, and the base of the PMP Air Shaft)
- Geologic and hydrogeologic investigations (to identify geologic characteristics in the three former disposal areas, characterize bedrock, and identify/investigate water-bearing fractures and voids)
- Soil and vadose zone investigations (to characterize soil quality in the three former disposal areas)
- Groundwater investigation and monitoring (to monitor groundwater quality at multiple discrete and isolated bedrock intervals, characterize groundwater flow pathways, and the connectivity between bedrock, overburden, surface water, and mine shafts)
- Human health and ecological risk assessments (to estimate the nature and probability of adverse health effects associated with exposure to Site-related constituents, now or in the future)

Focused Special Studies Completed as part of the remedial investigation:

- *Borehole geophysical logging and packer testing*
- *Bedrock fracture orientation measurements*
- *Environmental tracer and isotope studies*
- *Stable Isotope Probe and Bio-Trap® monitoring*
- *Groundwater level transducer and Peters Mine and Cannon Mine Shaft flow studies*
- *Geochemical study*

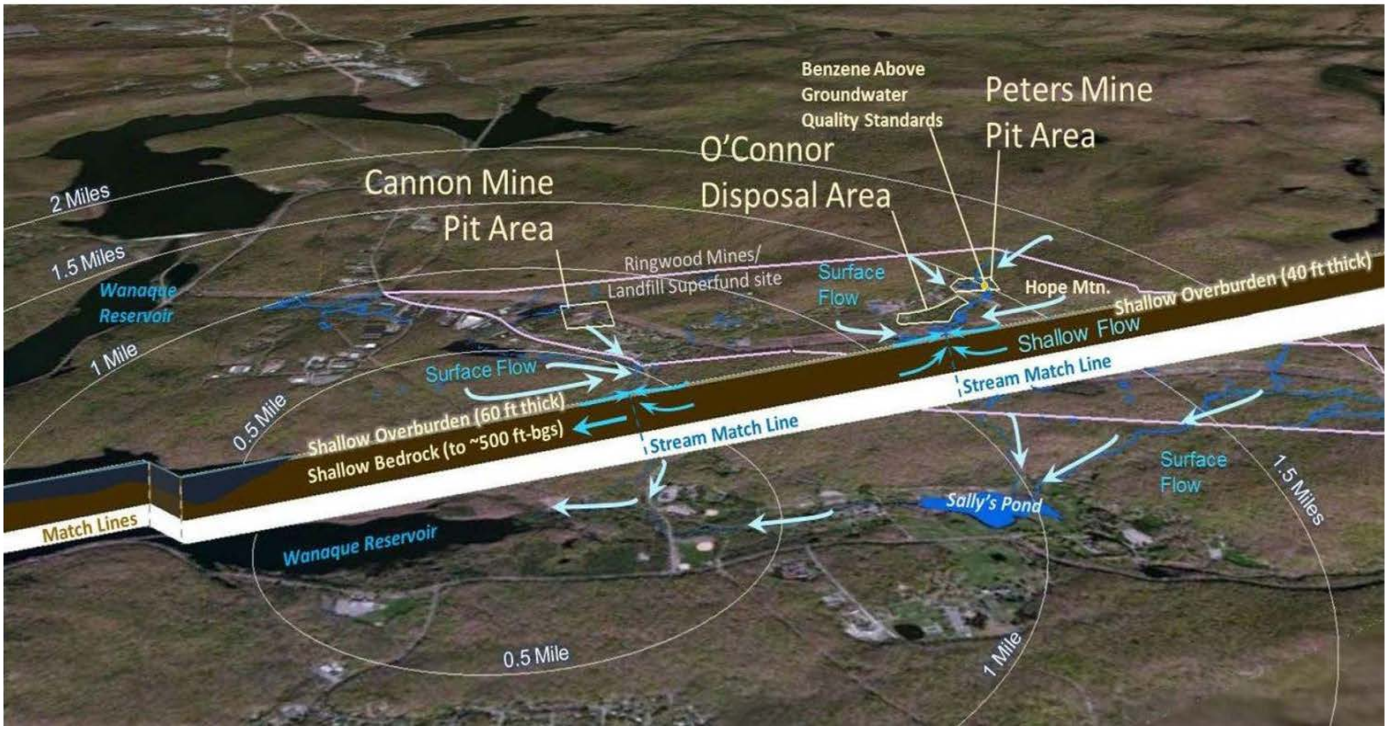
Results from these studies provide multiple lines of evidence to support the key findings of this RIR.

As part of these varied investigations, Ford conducted several focused and innovative studies to develop a firm understanding of groundwater transport that focused on the interconnectivity and hydraulic communication between groundwater and surface water across the Site (see summary above at right).

Key Findings

Key findings from the remedial investigation and the extensive historical record for the Site as a whole are as follows:

- **Source control has been conducted across the 455-acre Site** – residual conditions remain in the three former disposal areas – which together make up just 22 acres. Ford continues to investigate and remove dried paint pieces found outside the former disposal areas, as defined in the *Supplemental Reconnaissance Survey Work Plan* as approved by USEPA on October 22, 2013
- **The groundwater and surface water quality at the Site has been delineated through the wide-network of groundwater and surface water monitoring locations** – these locations will continue to be sampled and the data evaluated to monitor long and short term trends.
- **The occurrence, movement, and connectivity of groundwater in and between the bedrock and overburden layers at the Site is well understood**. Geophysical, environmental tracer, isotope, and geochemical studies reveal that groundwater from shallow fractured bedrock moves upward into overburden where groundwater then discharges to surface water. Deep bedrock groundwater studies reveal a potential upward gradient (potential for upward flow). However, well purging data show that yield is very low to negligible, revealing that actual flow through fractures at depth is negligible to non-existent. Groundwater and stormwater that infiltrated into the underground mine workings after cessation of operations is essentially trapped and held in storage, with little flow back out and into the fractures of the surrounding fractured bedrock aquifer.
- **The conceptual site model (CSM) describes the occurrence, distribution, and fate and transport of constituents in groundwater and surface water**. This model is described in more detail in the body of this RIR, and represents an assimilation of CSMs developed for PMP, CMP, and OCDA based on data available to date. The key elements of the conceptual site model are depicted on the diagram below – namely that there is negligible groundwater flow in the deep bedrock, minimal flow in shallow bedrock, and upward movement of groundwater from the shallow bedrock and overburden, and groundwater discharges to surface water streams that flow to Ringwood Creek. Natural recovery mechanisms at work under current conditions are limiting the migration of Site-related constituents in surface water and groundwater.



- **There are a limited number of Site-related constituents in groundwater and still fewer in surface water** – detections of Site-related constituents in groundwater are limited, infrequent, and sporadic. There is no definable plume of benzene, lead, or arsenic in groundwater.

- **Concentrations of benzene, lead, and arsenic – the key Site-related constituents – are declining or stable** at most locations due to natural attenuation processes at work under current Site conditions. Small increases in benzene concentrations were observed in shallow bedrock wells RW-6 and RW-6A (on the order of 0.5 to 12 micrograms per liter [µg/L]) in the PMP Area, and in deep bedrock well RW-8 (2 µg/L in November 2013). Additional monitoring will confirm whether these increases are isolated or part of a new trend that shows some small fluctuations in concentrations over time.

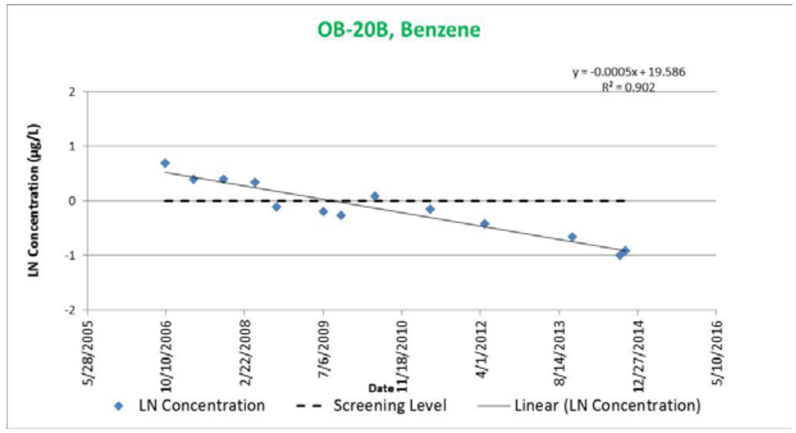
- **There are no cancer- or non-cancer-related health risks** to current residents living near that Site or recreating on the Site or to Site workers due to exposure to Site-related constituents based on conservative Site-specific exposure assumptions developed for the three landfill ACs. The scenario for the PMP Area, OCDA, and CMP Area showing potential risk (under very conservative assumptions) is the "hunter" scenario, due to repeated or chronic ingestion of low levels of lead, arsenic, and other metals contained in plant and game tissue.

- **Site-related constituents are found at or near the landfill areas**. There are no Site-related impacts to either the Wanaque Reservoir or the Borough of Ringwood's municipal wells. Moreover, the extensive network of monitoring wells in place at the Site are in the correct positions to serve as sentinels, and would provide early warning if conditions were ever to change. The transport of Site-related constituents in groundwater and surface water is limited by naturally occurring attenuation processes that are causing the biological degradation and volatilization of benzene and limiting/controlling the mobility of arsenic and lead. Nearly 30 years of groundwater and surface water data are available to corroborate the critical conclusion that the Wanaque Reservoir and the Borough of Ringwood's wells have not been and will not be impacted by Site-related constituents.

Benzene and the Peters Mine Pit Area

Benzene has been detected in groundwater primarily in the PMP Area, with concentrations ranging from 27 to 33 µg/L at the base of the air shaft and concentrations of less than 6 µg/L in the overburden aquifer adjacent to the landfill area. In the PMP area of the Site, shallow bedrock groundwater is moving upward (referred to as an upward vertical gradient while the deep bedrock groundwater has little to no movement/flow. There is evidence that a possible source of benzene in sediment is located at the bottom of the air shaft at the PMP, but there is limited hydraulic connection between groundwater in the air shaft and downgradient bedrock locations, as the low volume of flow is upward in the upper 150 feet in the flooded air shaft. In addition, the benzene in the air shaft is being effectively controlled by the presence of a thermocline at 180 feet below ground surface, and natural degradation processes (conclusively demonstrated in two of the special studies – the stable isotope probing and the Bio-Trap® work).

Overall, benzene in overburden groundwater appears to be attenuating. There have been no substantive increases in concentrations of benzene over the past 25 years, with exception to a few locations, including wells RW-6, RW-6A per sampling conducted in November 2013 and September 2014. The benzene concentration in RW-6A increased from 2.0 µg/L in April 2012 to 15 µg/L in November 2013, and 6.8 µg/L in October 2014. The benzene concentration in RW-6 increased slightly from an estimated value of 0.74 µg/L to 2.3 µg/L in November 2013 and 15.7 µg/L in October 2014. This increase of benzene observed at RW-6/6A well pair does not appear to correlate to a change in water levels or aqueous geochemistry. Additional groundwater monitoring at the PMP Area will be needed to assess whether this increase indicates a change or is just a temporary result.



Based on Linear Regression analysis, a statistically significant decreasing trend is documented at wells OB-20A and OB-20B, located down and cross-gradient of the PMP. In addition, benzene concentrations are decreasing at monitoring location OB-11R and decreasing statistically significantly at OB-27, indicating natural attenuation processes are occurring.

A forensic evaluation was conducted on the sediments at the base of the Peter's Mine air shaft to evaluate the source of benzene detected in sediment. The evaluation included a direct comparison of polycyclic aromatic hydrocarbons, a cluster analysis of metals, a direct comparison of metals concentration and distribution, and an evaluation of VOC and SVOC distributions. It was concluded that the sediment contains products related to manufactured gas plant sources (i.e., creosote, which is commonly found in mine timbers) and combustion sources (like urban dust/combustion from cars, gasoline-fired engines, or even fires), not paint waste, and that paint waste is likely not the source of benzene at the base of the air shaft.

As to surface water and seeps (wet areas where groundwater reaches the surface), low concentrations of benzene in groundwater is limited to the immediate vicinity of the PMP and is not detected downstream of the point where it discharges into Park Brook. The average benzene concentration at the seep located downgradient of the PMP at the Sludge Removal Area 3 (SR-3) Seep is 0.40 µg/L (below the 1 µg/L groundwater quality standard [GWQS]) over the last six monitoring events.

Arsenic and Lead

Both arsenic and lead have been detected in groundwater – arsenic at the PMP and the OCDA, lead inconsistently at various locations.

Metals are primarily found in "total" form, with limited detections of dissolved arsenic and lead above the GWQS. Data reveal that many of the metals results above groundwater standards are related to high turbidity (i.e., water containing metal-rich particulate matter yields concentrations that are biased high). The pH of groundwater also plays a role in metal concentrations found in the OCDA.

Filtering of samples can be effective in controlling turbidity influences in recent sampling events. However, even with filtration, sporadic concentrations at or above the GWQS have been observed. Geochemical studies indicate that the metals in groundwater are precipitating as solids under natural, oxidizing conditions in the immediate areas of the landfills of concern (a natural attenuation process).

Conclusions

Collectively, the body of data amassed over the past 30 years supports the overall conclusions that there are limited impacts associated with the Site-related constituents. The identified groundwater impacts are localized to the immediate area of the former disposal areas, and natural attenuation processes are at work, lessening the effects over time.

Studies show that:

- The existing well network is effective in monitoring the connectivity and potential flow pathways of Site-related constituents.

- The low constituent concentrations sporadically measured in groundwater are not leaving the Site.
- Natural biodegradation and attenuation processes are effectively controlling the constituents at the Site.
- Multiple lines of evidence provide sufficient support to proceed to the Feasibility Study stage for the Site groundwater.

Ringwood Mines | Landfill Site

Timeline

1700s to 1930s

- Ringwood Mines opened (1700s – 1930s)

1941 to 1983

- US Government operates mine for war efforts (1941 – 1958)
- Pittsburgh Pacific acquires mine (1958 – 1965)
- Ringwood Realty (Ford Subsidiary) acquires Site (1965)
- Ringwood Realty subdivides and divests some land (1965 – 1973)
- Bureau of Mine Safety Report identifies Refuse in Pits (1965)
- O'Connor Haulage contracts with Ford Mahwah to handle paint waste (1967 – 1971)
- Ringwood Solid Waste Authority operates municipal landfill at Site (1972 – 1976)
- Ford identifies Site to the USEPA (1981)
- NJDEP ranks the Site on the USEPA Hazardous Site Ranking System (1982)
- **Ringwood Site placed on NPL** (1983)

1984 to 1994

- Remedial Investigation (1984 – 1988)
- Paint waste removal action (1987 – 1988)
- Record of Decision, Feasibility Study, Risk Assessment (1988)
- Background Study (1989 – 1990)
- Five-year monitoring program (1989 – 1996)
- Paint waste excavation and removal action (1990 – 1991)
- **Ringwood Site deleted from the NPL** (1994)

1995 to 2006

- Post Environmental Monitoring Program (1995 – 2001)
- Paint waste removal action (1995)
- Paint waste removal action (1997 – 1998)
- Supplemental Site Investigation Work Plan (2004)
- Site-Wide Groundwater Sampling (2004 – present)
- Annual Site-Wide Groundwater Sampling (2004)
- Paint waste removal action (2004 – 2012)
- Ford signs Agreement on Consent (AOC) with USEPA (2005)
- Paint Waste Reconnaissance Survey (2005)
- Site-Wide Surface Water and Sediment Sampling (2005)
- Site Wide Test Pit Survey (2005 – 2008)
- **Ringwood Site placed back on the National Priorities List (NPL)** (2006)

2007 to 2011

- Investigation of Mine Tailing and Background Soils (2008)
- Supplemental Peters Mine Pit (PMP) Area Investigation (2008)
- Supplemental O'Connor Disposal Area (OCDA) Investigation (2008)
- Supplemental Cannon Mine Pit (CMP) Area Investigation (2008)
- Annual Site-Wide Groundwater Sampling (2009)
- Pesticides/herbicides removed from groundwater sampling (2009)
- Site-Wide Memorandum of Potential Exposure Pathways/Assumptions (2010)
- Groundwater sampling frequency changes from semi-annual to annual per USEPA (2010)
- PMP Area Feasibility Study (2013)
- PMP Pathway Analysis Report (2011)
- PMP Screening-Level Ecological Risk Assessment (2012)
- PMP Baseline Ecological Risk Assessment (2012)
- PMP Human Health Risk Assessment (2012)
- Traffic Study Analysis (2012)

2012 to Present

- Supplemental Site-Related Groundwater Investigation (2012 – present)
- CMP Pathway Analysis Report (2012)
- CMP Baseline Ecological Risk Assessment (2013)
- CMP Human Health Risk Assessment (2013)
- CMP Area Feasibility Study (2012 – present)
- OCDA Pathway Analysis Report (2012)
- OCDA Human Health Risk Assessment (2013
- CMP Baseline Ecological Risk Assessment (2013)
- OCDA Feasibility Study (2013)
- CMP Screening-Level Ecological Risk Assessment (2013)
- Site-wide Groundwater Human Health Risk Assessment (2013)
- Site-wide Groundwater Baseline Ecological Risk Assessment (2013)
- Additional Paint Waste Removal (2014)
- Paint Waste Reconnaissance Survey (2014)
- Sediment/Porewater Investigation (2014)

Note: this timeline presents a summary of the major milestones and key efforts & deliverables.

1. Introduction

ARCADIS U.S., Inc. (ARCADIS), on behalf of Ford Motor Company (Ford), has prepared this revised *Site-Related Groundwater Remedial Investigation Report* (RIR) for the Ringwood Mines/Landfill Superfund Site located in the Borough of Ringwood in Passaic County, New Jersey (Site). A Site location map is provided as Figure 1, the Site layout and investigation locations are shown on Figure 2, and a topographic map depicting Site features is presented on Figure 3.

This RIR has been prepared in accordance with the United States Environmental Protection Agency's (USEPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, EPA/540/G-89/004 (USEPA 1988a) and the Administrative Order on Consent (AOC) for the Site. USEPA and Ford entered into an AOC in 2005 to conduct supplemental investigations at the Site. In May 2010, the 2005 AOC was superseded by a revised AOC, which separated the Site into four Areas of Concern (ACs): Peters Mine Pit (PMP) Area, Cannon Mine Pit (CMP) Area, O'Connor Disposal Area (OCDA), and Site-Related Groundwater. The 2010 AOC required the preparation of separate RIRs, as well as additional submittals leading up to a final Feasibility Study (FS) for each AC. The draft RIR was submitted to USEPA on January 2, 2013. This RIR has been revised based on the USEPA comments provided to Ford on November 26, 2013 and a conference call held on December 23, 2013 to discuss USEPA comments.

A robust dataset has been compiled for the Site to evaluate a wide range of constituents in Site media. Based on evaluation of these data collected during comprehensive investigation activities, the primary constituents of concern (COC) are those detected most frequently in groundwater and surface water: benzene, arsenic, and lead. The remainder of this RIR summarizes and evaluates this extensive dataset and presents conclusions about the nature, occurrence and distribution of COCs with respect to Site groundwater and surface water.

The extensive groundwater investigation activities conducted at the Site since 2004 have been in accordance with the USEPA-approved Post-Environmental Monitoring Program Sampling Work Plan (Post-EMP Work Plan; ARCADIS 2004a) and USEPA-approved Groundwater Sampling Work Plan (ARCADIS 2006a), as well as the requested and approved work plan modifications (USEPA 2009) and the Proposed Supplemental Site-Related Groundwater Remedial Investigation Work Plan dated March 2012 (ARCADIS 2012a). In addition, the Site surface water investigation has been completed in accordance with the USEPA-approved Work Plan for the Stream Sediment/Surface Water Sampling Activities (ARCADIS 2005a), the Proposed Groundwater Sampling Modification comments provided by USEPA in 2011 (USEPA 2011), and the April 2014 Proposed Surface Water and Sediment Pore Water Investigation Work Plan (ARCADIS 2014). These work plans and the associated correspondence will be collectively referred to as the Work Plan throughout the remainder of this RIR.

1.1 Purpose of Report

The purpose of this RIR is to do the following:

- Provide a comprehensive summary of the scope, methods, and findings of the groundwater and surface water investigations Ford has conducted at the Site.
- Summarize the results of previous investigations.
- Describe the geologic and hydrogeologic features.
- Present an overview of the nature and extent of impacts at the Site and any potential risk to public health or the environment related to the release or potential release of any constituents at or from the Site.

1.2 Supporting Documents

This RIR incorporates the work plans, technical memoranda, and correspondence prepared for groundwater investigations and monitoring at the Site from 2005 to 2014. These documents are cited throughout this RIR as appropriate, and the full references are provided in Section 9.

1.3 Report Organization

The remainder of this RIR is organized as follows:

- Section 2, Site Description, discusses the Site features, describes the history of operations and disposal at the three ACs and the overall Site, identifies potential sources of COCs, and summarizes the completed environmental activities.
- Section 3, Physical Characteristics of the Study Area, describes the geological and hydrogeological characteristics of the Site, as well as demographics and key ecological features.
- Section 4, Remedial Investigation Summary, describes the groundwater and surface water investigations, as well as other investigations completed to support remedial decision-making for Site-related groundwater.
- Section 5, Remedial Investigation and Monitoring Results, presents the groundwater and surface water data collected from 2005 through 2014 and also presents data from other activities completed to support remedial decision-making.

- Section 6, Groundwater Flow, Connectivity, and Attenuation Evaluation, presents the methodology and results used to evaluate connectivity and natural attenuation mechanisms that influence the occurrence, fate, and transport of various constituents in groundwater and surface water at the Site.

- Section 7, Conceptual Site Model, presents a conceptual site model (CSM) for each AC as well as an overall CSM for Site-related groundwater.

- Section 8, Summary and Conclusions, presents the key findings to inform remedial decision-making for Site-related groundwater.

- Section 9, References, lists documents used in preparation of this document.

Tables and figures are also included to provide further detail, as appropriate, and a series of appendices has been complied to provide the supporting data for the discussions included in the main text. The appendices are as follows:

- Appendix A – Monitoring Well Construction Logs
- Appendix B – Previous Site Investigation Reports and Groundwater Technical Memoranda
- Appendix C - Arsenic Groundwater Analytical Results
- Appendix D – Downhole Geophysics Reports
- Appendix E – Borehole Geophysics Logging Report and Flow Measurements Collected Within the Cannon Mine (CM) and Peters Mine (PM) Air Shafts
- Appendix F - Summary of Results for All Constituents (2004 – 2014)
- Appendix G – Laboratory Analytical Reports
- Appendix H – Sediment Sampling Results
- Appendix I – Peters Mine Air Shaft Sediment Forensic Evaluation
- Appendix J – Benzene Trend Analysis
- Appendix K – SIP and Bio-Trap® Analysis Results Reports

2. Site Description

As shown on Figure 1, the Site is located in the New Jersey Highlands, a mountainous part of New Jersey. It is approximately 500 acres in size, is 0.5 mile wide, and approximately 1.5 miles long. The Site consists of moderately rugged forested areas, open areas of overgrown vegetation, abandoned mine shafts and surface pits, an air shaft, a closed municipal landfill, small surficial depositional areas, automobile carcasses, a municipal recycling center, the Borough of Ringwood Department of Public Works Garage, and residential properties. Ringwood State Park is located north and east of the Site.

The Site is bordered by mountainous ridges to the west (Whaleback Mountain, Mine Hill) and north (Hope Mountain, Unnamed Mountain) and lower hills and ridges to the east and south, and is situated on the western side of a valley defined by the Wanaque River watershed. There are four primary streams in different parts of the Site that are tributaries to Ringwood Creek: Mine Brook (western and southern areas), Peters Mine Brook (a drainage swale in the central part of the Site), Park Brook (north-central area), and an unnamed tributary of Ringwood Creek identified as North Brook (northern area). The Ringwood Creek watershed drains to the Wanaque Reservoir, which, as shown on Figure 1, is nearly 2 miles from the PMP Area and approximately 0.75 mile from the Site boundary in the CMP Area.

There are paved roads in the residential areas and leading to former mining areas. These roads are Peters Mine Road, Cannon Mine Road, Van Dunk Lane, Sheehan Drive, Milligan Drive, Horseshoe Bend Road, and Petzold Avenue. There are also many former mine roads and trails; some are dirt roads and others are covered with asphalt, gravel, or mine tailings. A few of the trails and former mine roads are in various states of natural reclamation.

The Borough of Ringwood Department of Public Works Garage is located near the intersection of Peters Mine Road and Margaret King Avenue, and the Borough Recycling Center is located approximately 0.5 mile north on Peters Mine Road. There is a Public Service Electric and Gas Company (PSE&G) power substation on the east side of Peters Mine Road, approximately 400 yards north of the Margaret King Avenue intersection.

2.1 Site History

The Ringwood Mines/Landfill Site is a historical iron mining site that operated from the 1700s until the 1950s. In 1942, the U.S. Government purchased the Upper Ringwood Area (approximately 870 acres) and invested heavily in the mines to prepare them for potential use in World War II.

Activities conducted by the U.S. Government’s lessee, the Alan Wood Steel Company, from 1942 until 1945 included the reconstruction of a number of mine-related structures; refurbishment of the mines’ water supply system; dewatering of the mines; excavation and onsite disposal of more than

100,000 cubic yards of waste rock and mine tailings (pulverized and small pieces of mined rock and mineral materials discarded after separation from iron ore during the mining process); reopening, enlarging, reconditioning, and extending of the original mine levels; production and processing of some ore; and related activities. The U.S. Government sold the mines in 1947 to a private party, but the property reverted to the U.S. Government 1 year later after the private party filed for bankruptcy. As a result of this long history of mining operations, large volumes of mine tailings were disposed of onsite and then re-worked or scattered across the Site.

In 1958, the U.S. Government sold the property to Pittsburgh Pacific Company, and in 1965 Pittsburgh Pacific Company sold the property to the Ringwood Realty Corporation, a former subsidiary of Ford. In 1967, Ringwood Realty contracted O'Connor Trucking and Haulage Company (O'Connor) to dispose of paper, cardboard, wood, metal, plastic scrap, general trash, paint waste, scrap drums, car parts, and other non-liquid plant wastes from Ford's former Mahwah assembly plant. The O'Connor agreement ran from 1967 until 1971, and required O'Connor to properly dispose of Ford wastes at three locations on the Ringwood Site: the PMP Area, the CMP Area, and the OCDA (these areas are discussed in more detail in Section 2.3). O'Connor's disposal activities during this time were approved by state and local officials.

In November 1970, Ringwood Realty donated 290 acres of the Site to the Ringwood Solid Waste Management Authority. By November 1971, Ringwood Realty had sold all but 145 acres of the Site, and by December 1973 Ringwood Realty no longer owned any portion of the Site. Dumping by others occurred before, during, and after the 4-year period during which Ford-related wastes were disposed of at the Site.

Today, this former mining Site has numerous former mine pits, prospect pits, underground mine workings, and mine waste disposal areas. The material present in the ACs (PMP, CMP, and OCDA) consists of fill cover soil, mine tailings (PMP Area and OCDA only), construction and demolition debris, general manufacturing wastes, general municipal-type wastes, dried paint pieces (PMP Area and OCDA only), drum remnants, and miscellaneous fill. After disposal ceased, these ACs were graded and an approximately 2-foot clean fill cap was placed.

2.2 Constituents of Concern and Sources

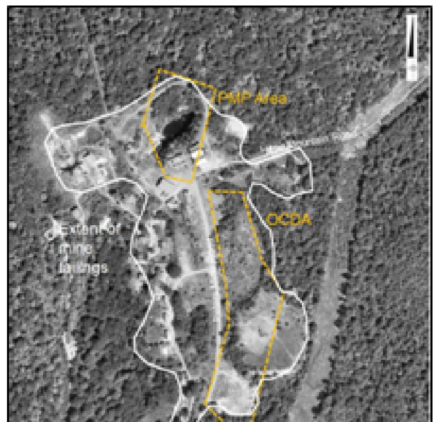
The robust dataset for the Site includes analysis of many constituents. However, based on the evaluation of multiple groundwater studies, ongoing groundwater monitoring, and USEPA-approved RIs for the CMP, PMP, and OCDA, the most frequently detected constituents are the primary COCs for Site-related groundwater: benzene, lead, and arsenic. Sections 4 and 5 will present a comprehensive look at groundwater and surface water investigations and data, and analyses of trends and nature and extent and the CSM will focus on these three COCs.

2.2.1 Potential Sources of COCs

The Site has a long history of disposal operations by several entities. Sources of the COCs can be related to some or all of the associated operations, including:

- Mining operations
- Post-mining automobile disposal and structure fires
- Solid waste disposal
- Mahwah assembly plant waste disposal

As previously described, the 500-acre Site is primarily forested land, untouched by these historical operations. However, as described in more detail below, historical disposal activities and practices have impacted the mining pits (PMP and CMP), mine disposal areas (OCDA), and disperse paint waste disposal areas, identified as sludge removal (SR) areas.



Approximate extent of mine tailings in the PMP and OCDA areas based on historical aerial photos and historical maps; shown on 1966 aerial.

Mining Operations

As a result of mining operations from the 1700s through the 1950s, mine tailings were disposed over a broad area of the Site. These mine tailings later became commingled in some places with dried paint pieces, Ford solid waste, and municipal refuse at the Site. Arsenic and lead are present in these mine tailings as well as native soil and host rock; however, lead concentrations are much lower than the New Jersey's Residential Direct Contact Remediation Standard in native soil, rock, and mine tailings (ARCADIS 2008a, 2008b). In addition to the introduction of mine tailings at the Site, the mining operations commonly used petrochemicals and fuels to support the mining activities. Evidence of this was uncovered in 2006, when four underground storage tanks (USTs) were discovered (and subsequently removed and disposed of by Ford) during a soil removal action along the north side of PMP. Subsequent research revealed that these USTs were likely installed in the mid to late 1940s, when the U.S. Government was renovating Peters Mine. A historical Ringwood Realty map shows that they were located adjacent to a small shed-like structure identified on the legend as an "Oil and Grease Shed". Aerial photographs from 1951 also reveal staining on the ground

Mine tailings at the Site.

close to the USTs. Based on water samples collected from inside the tanks analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPH), polychlorinated biphenyls (PCBs), and metals, it appears that the USTs were used to store diesel fuel to run construction and mine equipment, and possibly power electric generators. Use of other oils and grease products, and the residuals associated with the materials and machinery left behind when the mine was abandoned, also present potential sources of benzene and lead to the environment.

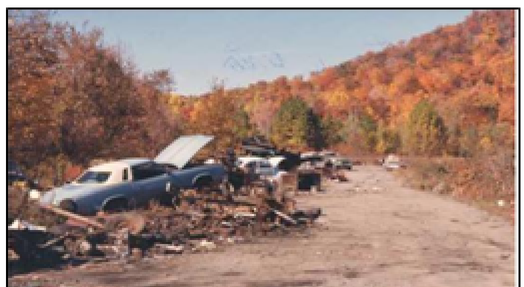
View of USTs once used to store fuel during mining operations uncovered at PMP in 2006.

Mining operations were also supported by an on-site power plant that was located on the southwest side of the pit (as shown on 1944 mine maps). It is unclear at this time whether the plant was supported by coal, fuel oil, or both.

At the end of the time period when mine operations ceased (in the 1950s), a large fire burned the PMP mill building and some of the support buildings connected by conveyor. Today, some of the charred remains and burnt wood can be found north of the former mill building. Burnt wood has also been found in test trenches installed in the OCDA.

Post-mining Automobile Disposal and Structure Fires

There is documented evidence that junked cars were placed in the mine pits and other areas of the Site. In a 1965 article in the Patterson Morning Call, Frank Lynford, vice-president of Ringwood Realty, estimated the number of abandoned cars to be more than 10,000 (Yesenosky 1965). Historical junk car disposal was also documented by the New Jersey Mine Safety Bureau in 1964.



Junked car and other debris along Peter's Mine Road.

A major fire at the Peters Mine occurred in July 1964, burning buildings and some of the mine pit structure (Herald News, July 6, 1964). Historical newspaper articles also document numerous fires in the Cannon Mine Pit during the period of solid waste disposal (Suburban Sunday Trend, March 1, 1970).

Waste observed in OCDA-rail car axel (right) and household/industrial debris with daily cover (above)

Solid Waste Disposal

As previously described, solid waste was disposed of at the Site before, during, and after the 4-year period during which Ford-related wastes were disposed of at the Site. The Site has also been subject to widespread dumping by the public. Waste materials include abandoned automobiles, white goods, tires, household trash, and general debris.

Mahwah Facility Disposal

As described previously, Ford contracted O'Connor to dispose of paint waste and other non-liquid plant wastes from Ford's former Mahwah assembly plant at the three ACs from 1967 until 1971. There is also evidence that waste was disposed in other areas readily accessible by dump trucks. Further, some of the waste, including dried paint pieces, was likely relocated by construction crews and others when fill material was transferred to other locations on the Site. The dried paint pieces found in areas outside the ACs—referred to as the SR areas—have been removed and disposed offsite. Paint waste can contain petroleum-related VOCs and SVOCs, along with antimony, arsenic, barium, chromium, and lead.

Paint waste was observed as a solid mass that resembles asphalt and often exhibits a weathered gray color. Shown here (circled) among rocks and other debris is a small piece of paint waste that was removed and disposed of offsite during removal operations.

Source removal activities to address Ford-related disposal at the Site has resulted in the removal of over 50,400 tons of surficial paint waste, soil, and other waste materials. Ford has and will continue to remove additional dried paint pieces if any are discovered at the Site.

Disposal activities, other than Ford's paint waste disposal, may have also contributed to environmental impacts at the Site. The focus of this RIR is on the characterization of groundwater and surface water as it relates to paint waste disposed by Ford; however, the contribution of background conditions due to mine tailings and other disposal operations are also discussed, as appropriate.

2.3 Areas of Concern

ACs were identified for the Site in accordance with the AOC for the Site. These include the PMP Area, CMP Area, and the OCDA. These are recognized as potential sources of COCs to groundwater and are fully evaluated in this RIR. This section provides an overview of each area.

2.3.1 Peters Mine Pit Area

The Peters Mine was one of the two most productive magnetite iron ore mines on the Site and was in operation from the mid-1700s until the 1930s. The host rocks for the magnetite iron ore are foliated gneiss, amphibolites, and pegmatite. Ownership of the PMP Area is currently divided between the Borough of Ringwood and the New Jersey Department of Environmental Protection (NJDEP), which owns Ringwood State Park.

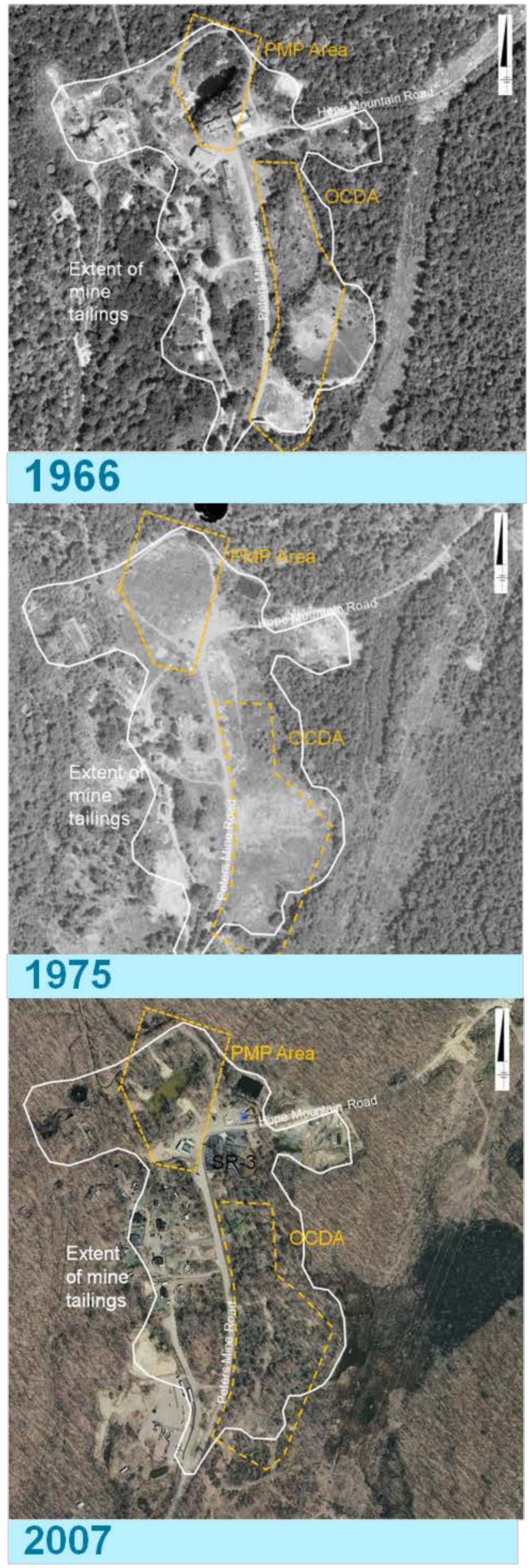
The Peters Mine consisted of an open pit with a shaft extending under Hope Mountain from the base of the pit. In 1961, when maintenance for a possible restart of mining operations was discontinued, the mine characteristics were as follows:

- Top of pit opening – 375 feet long (striking southwest-northeast) and up to 200 feet wide.
- Base of pit – approximately 375 feet long, up to 80 feet wide, and approximately 90 feet deep.
- Inclined mine shaft – 2,600 feet long and reportedly 1,500 feet below ground surface (bgs) at its deepest point below Hope Mountain.
- The incline shaft trends approximately N40 ^{o}E and dips at approximately 35 degrees to the northeast. A 230-foot vertical air shaft met the inclined shaft approximately 250 feet north of the pit (Hotz 1953). It was reported that, during the operation of the mine, operators were able to keep the mine drained by pumping groundwater from the mine structure at a rate of approximately 53.5 gallons per minute (gpm) based on the estimated water infill rate (Getz 1965).
- The underground workings of Peters Mine extend down through 17 levels of tunnels to access the iron ore shoot. The ore shoots are mostly mined out (called stopes when mined) above the Level 9 tunnel (Hotz 1953); therefore, the tunnels and stopes are void spaces in the bedrock

that are now filled with groundwater. The open tunnels and stopes associated with the mine are estimated to hold approximately 213,000,000 gallons of groundwater (Getz 1965).

- A flooded air shaft is located adjacent to the pit. The opening (at ground surface) is approximately 15 feet by 15 feet wide. Based on downhole logging, the shaft extends approximately 232 feet bgs. (Note that mining records indicate that the shaft may have originally extended down to 285 feet bgs).

This shaft was tested for a potential water resource during a time of severe drought in 1980, when the Ringwood Fire Department pumped approximately 420,000 gallons from the base of the shaft. This had little impact on the water level, and revealed concentrations of VOCs (before and after the pumping) similar to that observed today (Brimer 1980). Mine buildings and structures occupied areas southeast and northwest of the PMP Area through at least 1961. Comparison of the 1966 and 1967 aerial photographs indicates that the majority of these buildings were demolished during that time period.



In a 2005 affidavit, Mr. Russ Kerestes, a former vice president of the O'Connor Trucking and Haulage Company, stated that the inclined, concrete mine shaft penetrating the base of the PMP was sealed prior to beginning waste disposal in 1967. Documentation to confirm the method used to seal the shaft, or to determine whether the seal is watertight, is not available.

Between December 1967 and April 1971, the PMP was used for the disposal of solid wastes from the former Mahwah assembly plant. A 1966 aerial photograph indicates a pool of water located within the lower portion of the PMP. By 1973, the pit was filled to the level of the surrounding land surface and capped with earthen material.

Subsequent settling of the pit fill is evident in the depressed contours in the PMP Area, as shown on the 1984 topographic map prepared as part of the RI conducted by Ford from 1984 to 1988. Settlement of the fill has continued over recent years, and currently, there is a 300-foot-long pond located in what was once the deepest part of the PMP (Figure 4).

The PMP Area is located at the head of a small valley drained by Park Brook. This small valley is a branch off the main valley, which is drained by Ringwood Creek. Based on the drilling logs for monitoring wells RW-3 and OB-14B, the Park Brook valley floor is underlain by deposits of unconsolidated sediments above the bedrock, with the following materials encountered from the base of the valley in ascending order: fine-grained glacial till, poorly sorted gravel till and stream deposits, and mining tailings. These deposits have a total thickness of 50 or more feet depending upon location.

Groundwater in the unconsolidated overburden fill and sediments in the PMP Area occurs under unconfined conditions at depths of approximately 15 feet bgs. Data generated during the RI indicates that the pond water surface within the former PMP mine pit is a surface expression of the unconfined, overburden water table. Based on topography and measurements from groundwater monitoring wells within the PMP Area, the unconfined, overburden groundwater flows in a southeasterly direction across the PMP Area (ARCADIS 2005b).

2.3.2 Cannon Mine Pit Area

The CMP is located in the southwestern-most portion of the Site near the cul-de-sac at the end of Van Dunk Lane. The location and features of the CMP are shown on Figure 5. As shown, the CMP is located west of Van Dunk Lane and east/southeast of Sludge Removal Area 6 (SR-6). The characteristics of the CMP are as follows:

- CMP Area – mostly open field surrounded by a chain-link fence; includes disturbed areas, such as access roads and piles of rock.
- Pit – approximately 150 feet wide by 300 feet long and between 140 and 180 feet deep.
- Vertical mine shaft – located approximately 500 feet east of the pit at the intersection of Van Dunk Lane and Milligan Lane. The vertical shaft is approximately 500 feet deep and currently sealed with railroad ties and a 6-inch-thick concrete slab, which is located at approximately 3 feet bgs.

- The ore shoots are mostly mined out where exploited (Hotz 1953); therefore, these tunnels and stopes are void spaces in the bedrock and now filled with groundwater. The groundwater infill rate at Cannon was estimated at 24.7 gpm (Getz 1965).

- The underground workings of the Cannon Mine are estimated to hold 49,000,000 gallons of groundwater (Getz 1965) with four levels of tunnels to access the iron ore shoots below the pit that extend to an approximate depth of 500 feet bgs.

Based on historical records, the CMP was excavated to a depth of approximately 140 to 180 feet bgs. The mined ore bodies are pitched northeast at an angle of approximately 45 degrees. Review of existing information regarding the CMP indicates that there was a shaft at the base of the pit. At the surface, the combined CMP and London Mine Pit opening was approximately 200 feet by 140 feet. The CMP was connected to other mine pits in the vicinity, including the blue pit, little blue pit, hard pit, and mule pit, through a series of tunnels completed within two levels of the mine. Level one could be accessed through an opening at the bottom of the CMP, and both could be accessed through a lift at the CM Shaft located at the intersection of Van Dunk Lane and Milligan Lane.

As part of the RI for the CMP Area, historical records regarding mining activities and mine closure were reviewed. Memoranda regarding closure of the Cannon Mine and New London Pit by the New Jersey Mine Safety Bureau are included in Appendix A of the *Remedial Investigation Report for the Cannon Mine Pit Area* (CMP RIR; ARCADIS 2013b). Review of these records indicates that the CMP was backfilled to grade with a combination of rock blasted from the sides of the pit wall, municipal-type and industrial solid waste, and imported fill soil. The historical records indicate that three blasting events took place close to the CMP beginning between September 21, 1965 and November 16, 1965. The quantity of rock rubble generated from blasting the mine pit walls was only sufficient to partially backfill the CMP. Imported fill material, consisting of solid waste and cover soil, was placed on top of the rock rubble to backfill the pit to grade. Because the blasting began prior to O'Connor's contract with Ford and blast rock was encountered beneath the fill materials, the blasting of the pit predates disposal of waste material by Ford in the CMP.

The historical records also indicate that the New London Pit, located immediately northwest of the CMP, was closed in a similar manner by blast rock and that "the small slope at the bottom of the pit is well blocked with massive rock" (see memorandum titled The Safeguarding of Abandoned Mine Holes, Ringwood, Passaic County, September 21, 1965). A supplemental test pit investigation was conducted within the New London Pit in March 2011 and confirmed that the pit was filled to the surface with blast rock.

2.3.3 O'Connor Disposal Area

The OCDA was used during active mine operations as a "slime pond" for the settlement of waste mine tailings from the wet ore processing operations. "Slime" is a mining industry term that refers to silt size and finer mine tailings. Based on visual inspection of the OCDA, the slime pond berm is still present along the eastern perimeter of the OCDA adjacent to Park Brook.

While solid wastes from the Mahwah assembly plant were disposed in the three areas from 1967 until 1971, the OCDA was used toward the end of the 4-year period because the PMP Area was full.

As detailed in the *Remedial Investigation Report for the O'Connor Disposal Area* (OCDA RIR; ARCADIS 2013c), test trenching and test pitting events conducted as part of the RI within the OCDA showed that, at many locations within the OCDA, fill material contained a varied abundance of debris (including refuse and rubbish) that was intermixed with mine tailings and reworked soil. The uppermost landfill layer is extensive and is consistent topographically with the former "slime" tailings pond and other mine tailings disposal areas shown on historical mine maps, which define most of the OCDA. Miscellaneous debris material was encountered at almost every test pit or trench location within the boundaries of the OCDA. The landfilled materials included general trash (carpet, cloth, paper, cardboard, etc.), plastic bits and bags, tires, glass, foam, scrap wood, fiberglass or mineral wool insulation, paint waste, metal fragments and scrap, automobile debris, and miscellaneous junked appliances (white goods). Overall, soil cover and distinct layering patterns were difficult to distinguish because the fill material appeared to have been extensively reworked, causing intermixing of debris and soil from layers above and below.

The lateral and vertical extent of former landfilling operations was clearly delineated at most locations because the test trenches and test pits were terminated 1 or more feet into native soil, undisturbed mine tailings, or undisturbed mine waste rock.

2.4 Completed Environmental Activities

In 1983, USEPA added the Site to the National Priorities List (NPL) of abandoned hazardous waste sites. Environmental investigation of the Site began that same year, when Woodward-Clyde Consultants (WCC) was retained to perform RI activities at the Site.

The WCC investigation was conducted in phases, as summarized below. The details of the investigation are provided in WCC's Final Remedial Investigation Report (WCC 1988).

- Phase I (1983 to 1984) involved the acquisition of information necessary to generate a site-specific work plan for conducting Phase II investigations.
- Phase II (1984) involved gathering field data to delineate the nature and extent of impacts at the Site.

- Phase III (1986) continued the Phase II investigation work to further evaluate the nature and extent of residual impacts at the Site.

- Focused Removal Program (1987 to 1988) involved excavating four locations and removing, transporting, and disposing off site a total of 11,340 tons (approximately 7,000 cubic yards) of dried paint waste and impacted soil near the OCDA.

- Phase IV (1988) involved final confirmatory sampling to document post-excavation conditions at the Site. This phase was designed to confirm the data from previous sampling events.

Upon completion of these investigations, USEPA identified a remedial action alternative based on its review of the findings of the investigations and risk assessment and the post-removal action sampling data from paint waste areas. After reviewing comments from the public and NJDEP, USEPA issued a Record of Decision (ROD) for the Site in September 1988 (USEPA 1988b). The components of the ROD consisted of:

- Natural attenuation to achieve groundwater quality objectives in the upper aquifer (overburden) at the PMP Area

- Implementation of a long-term surface water and groundwater monitoring program (post-EMP) at the PMP Area to verify that natural attenuation was a protective final remedy for groundwater

- Confirmatory sampling and removal of impacted soil, if warranted, to confirm that the landfill areas were in compliance with NJDEP soil cleanup objectives.

In 1989, USEPA directed Ford to implement the remedy described in the ROD. Ford re-sampled soil from the excavated paint waste locations in the PMP Area and implemented a groundwater monitoring program. The confirmatory soil sampling showed that NJDEP soil cleanup objectives had been achieved. The 5-year EMP program consisted of sampling eight select overburden monitoring wells, nine select downgradient potable wells (a tenth potable well was taken out of service by the owner in 1992), and surface water tributaries to the Wanaque Reservoir. The EMP required quarterly sampling of groundwater and surface water during the first year and semi-annually for the subsequent 4 years. Ford conducted the quarterly EMP groundwater sampling events in 1990 with semi-annual sampling conducted in 1992 through 1995.

After the first year of quarterly sampling, the EMP was re-evaluated (WCC 1990), and surface water sampling was discontinued because the surface water sample analyses showed no exceedances of any NJDEP surface water criteria. Also, SVOCs were removed from the analytical parameter list, leaving VOCs, metals, and cyanide as the remaining parameters for groundwater monitoring.

Results of the 5-year EMP indicated that concentrations of constituents had not increased in Site monitoring wells and were only sporadically detected. In addition, site-related constituents were not detected in the potable wells sampled during the EMP. As a result of RI and remedial action activities completed by Ford, USEPA removed the Site from the NPL in November 1994, and it was de-listed as a Superfund site.

In 1998, USEPA requested two additional groundwater and surface water sampling events as a result of lead and arsenic detections in four on-site monitoring wells. Ford re-sampled those wells in August 1999 and April 2000 using low-flow purging techniques to reduce sample turbidity. In April 2000, Ford also sampled three surface water locations. The analytical results indicated that concentrations of both lead and arsenic were lower than the health-based criteria, except for arsenic detected in one monitoring well.

In December 2001, Ford submitted the *Final Summary Report for Post-Environmental Monitoring Program Activities* to USEPA (ARCADIS G&M 2001). The report provided a summary of all the EMP sampling, a background groundwater quality study, low-flow sampling groundwater analytical results, a trace element study, surface water analytical results, and a risk assessment.

In 2002, USEPA concluded, and NJDEP concurred, that the 5-year EMP was complete. This determination was based on the analytical results generated from 1990 through 2000 and the fact that all on-site residents were supplied with municipal water because groundwater at the Site is *not* used as a potable water source. USEPA noted that the North Jersey District Water Supply Commission did not report any concerns regarding the Wanaque Reservoir, which is one of two sources of municipal drinking water. The Borough of Ringwood municipal production wells, which are located in a different watershed approximately 2 miles from the Site, is the other (and primary) source of drinking water for Borough residents.

Ford removed 11,300 tons of solidified paint waste in 1987 and 1988, and removed approximately 660 additional tons of paint waste during three separate removal actions in 1990 to 1991, 1995, and 1997 to 1998. Between 2004 and 2012, Ford removed approximately 50,000 tons of additional surficial paint waste, soil, and other waste materials from the Site. During that period, USEPA re-listed the Site on the NPL on September 26, 2006.

Ford and USEPA entered into the 2005 AOC to conduct a second comprehensive RI of the Site to confirm that any other wastes remaining following the initial removal action and RI were identified. As described in Section 1, in May 2010, the 2005 AOC was superseded by a revised AOC, which separated the Site into four ACs, including the PMP Area, the OCDA, the CMP Area, and Site-Related Groundwater. This RIR describes the second RI work scope, methods, and findings for work completed pursuant to the AOC, including source identification and characterization; geologic and hydrogeologic investigations; and surface water and groundwater flow pathway, connectivity, and quality investigations.

3. Physical Characteristics of the Study Area

3.1 Surface Features

The Site consists of moderately rugged forests with open areas of overgrown vegetation. The terrain is mountainous, with peaks up to 900 feet above mean sea level (amsl) and valleys that are generally less than 500 feet in elevation. There are four drainage basins within the Site and, as a result, there are four streams that essentially drain the Site. They include Mine Brook, Peters Mine Brook, Park Brook, and North Brook. Peters Mine Brook joins Mine Brook along the southern Site boundary. Mine Brook flows into Ringwood Creek, just upstream from the Wanaque Reservoir. Park Brook and North Brook each flow into Furnace Dam Pond to the southeast of the Site, and subsequently to the Ringwood River, approximately 1 mile upstream from its confluence with the Wanaque Reservoir.

There are abandoned mine shafts and surface pits, landfills, industrial refuse disposal areas, a municipal recycling center, and residential lots within the Site boundaries. There are also several open mine pits that were either filled and restored to grade or are now small pools or ponds of standing water.

3.2 Meteorology

New Jersey is located along the northeastern coast of the United States. Due to this geographic location, New Jersey is influenced by wet, dry, hot, and cold airstreams, and daily weather varies widely. Average annual precipitation is between 43 and 48 inches within the Northern Highlands Physiographic Province, where the Site is located, however, Ringwood averages 51 inches per year. Snow may fall from approximately October 15 to April 30 in the Highlands Physiographic Province of New Jersey. The overall climate in the vicinity of the Site is characterized as "continental temperate."

Although New Jersey is a small state, it has five distinct climate regions, which are influenced by the state's topography, geology, distance from the Atlantic Ocean, and prevailing atmospheric flow patterns, producing distinct variations in daily weather among the climate regions. The five regions are: Northern, Central, Pine Barrens, Southwest, and Coastal. Ringwood, in northeastern Passaic County, is in the Northern zone climate region (Office of the New Jersey State Climatologist at Rutgers University 2012).

The Northern climate zone consists primarily of elevated highlands and valleys that are part of the Appalachian Uplands Physiographic Province. This zone is influenced less by the Atlantic Ocean than other climate zones in the state, except when there are strong easterly winds. The terrain causes the northern zone to have colder average temperatures than the rest of the state, as well as increased precipitation. Cyclonic storms cause most of the precipitation in the Northern zone, except during warmer months when thunderstorms are responsible for most of the rainfall.

3.3 Surface Water Hydrology

Generally, surface water at the Site flows from the north and northwest via wetlands and shallow streams to the south and southeast. The flowing surface water bodies at the Site are Park Brook, Peters Mine Brook, Mine Brook, and an unnamed tributary of Ringwood Creek referred to for purposes of this RIR as North Brook. Wetland areas are primarily located in the vicinity of the surface waters in the northeastern, east-central, and southwestern parts of the Site.

The surface water bodies are recharged directly by precipitation and groundwater discharge. During times of extended or heavy precipitation, the streams are high-energy types. Stream flow is perennial in the lower elevation portions of the Site. Stream flow is ephemeral in the narrow stream corridors north of the PMP Area, typically above an approximate elevation of 525 feet amsl, with little to no surface water observed during dry summer and early fall months.

The surface water bodies eventually drain to Ringwood Creek and are part of the Wanaque River watershed. All of the surface water bodies are classified as freshwater, trout maintenance by NJDEP.

Some of the surface water hydrology at and in the vicinity of the Site has been altered by historical development, such as road construction activities along Peters Mine Road, which has turned Peters Mine Brook into a drainage ditch. The Park Brook channel, which flows through the PMP Area, was re-routed by miners more than 150 years ago so that the mine pit could be excavated.

Peters Mine Pit Area

As shown on Figures 2 and 3, surface water bodies at the PMP Area include Park Brook (which flows around the pit on the north and east sides), two seeps in the slope of the Sludge Removal Area 3 (SR-3) area (adjacent to and downgradient of the mine pit), and a pond at the base of the SR-3 area. Data generated during the RI indicate that Park Brook is a perennial stream downstream of the PM Air Shaft, but the stream bed has been observed to be dry upstream of the air shaft during late summer and early fall months. Park Brook flows to the east and south as it bends around the PMP. Park Brook continues along a southeasterly path, flows past the OCDA, and eventually drains into Sally’s Pond.

Cannon Mine Pit Area

As shown on Figures 2 and 3, Mine Brook is the surface water body located to the west and south of the CMP Area. It flows south along the west side of the CMP Area and passes under Margaret

King Boulevard. There, it turns to the east and north for a short distance as it wraps around the ridge where the CMP Area is located before continuing to the southeast towards the Wanaque Reservoir.

O'Connor Disposal Area

Surface water bodies in the vicinity of the OCDA include Park Brook, which flows to the east of the area, a beaver pond within Park Brook east of the central part of the OCDA, and wetland areas in the northeastern and southeastern parts of the OCDA. Park Brook flows to the south in the OCDA before turning to the southeast and flowing to Sally's Pond.

3.4 Geology

The Site is located in the southeastern extension of the New England Highlands Physiographic Province. The portion located in New Jersey is known as the New Jersey Highlands. In areas of well-foliated gneiss, the topography of the New Jersey Highlands consists of northeast-southwest trending parallel ridges. The more common, less foliated gneiss forms rounded or broad-topped topographic highs. Granite gneiss and pegmatite form sharp ridges separated by narrow troughs underlain by less resistant gneiss. Major cross faults are visible as trench-like features that interrupt drainage. Those faults generally strike approximately east-west across the predominant northeast strike of the major ridges and valleys (Hotz 1953).

Structural features of the New Jersey Highlands, which are regionally related either spatially or tectonically, include folds, faults, lineation trends, and jointing. The New Jersey Highlands has experienced a complex history of folding and faulting, the result of both Precambrian and post-Precambrian tectonism. The formation of the New Jersey Highlands and the associated faulting and folding, which produced structural complexities in the region, occurred during the closing periods of the Paleozoic Era concurrent with the formation of the Appalachian Mountains (WCC 1988).

The New Jersey Highlands in Passaic County are drained by the Pequannock, Wanaque, and Ramapo Rivers, which ultimately join to form the Pompton River, a tributary of the Passaic River. The drainage pattern north of the terminal moraine in the New Jersey Highlands is classified as deranged, and is marked by many poorly drained areas of lakes and swamps. Greenwood Lake and Lake Hopatcong are large lakes formed by the blocking of pre-glacial drainage courses. South of the terminal moraine, stream drainage generally follows structural valleys toward the southwest (WCC 1988).

Unconsolidated soil and sediment deposits are primarily confined to the stream valleys and corridors. Based on the findings of the RI, the unconsolidated deposits are thickest in the eastern and southern parts of the Site. The overburden ranges from approximately 25 to 50 feet thick. The overburden consists of the Rahway Till dating from the Pleistocene age and is reddish-brown, light reddish-brown, reddish-yellow silty sand to sandy silt containing some to many sub-round and sub-angular pebbles and few sub-rounded boulders. The matrix is compact, non-plastic to slightly plastic with coarse sub-horizontal fissile structures, and the clasts are composed of red and gray sandstone and siltstone, gray gneiss, and white to gray quartz and quartzite gravel. Boulders are mainly gneiss, and a few are quartzite or gray and red sandstone (Stanford 2002).

Bedrock is encountered at approximately 25 to 50 feet bgs. Bedrock consists of Mesoproterozoic age metasedimentary rocks of the Vernon Supersuite and gneisses of the Losee Metamorphic Suite, approximately 1.3 billion years old. The rock primarily consists of calc-alkaline and plagioclase gneisses. There are occurrences of pegmatite, pyroxene-amphibolites, biotite-quartz feldspar gneiss, and magnetite iron ore. The structural nature of bedrock at the Site is complex. The gneisses are moderately to well foliated, have mineral lineation, and display evidence of three distinct folding events. Joints are prevalent in the bedrock and are characteristically moderate to well developed, planar, typically unmineralized, and moderately to steeply dipping with spacing from 1 foot to several tens of feet (Volkert 2008)

The iron ore found in Ringwood is thought to be hydrothermal deposits consisting primarily of magnetite that replaced pyroxene amphibolites and skarn rocks. The iron ore formed around the same time as emplacement of granite and pegmatite, approximately 950 million years ago.

3.5 Soils

Unconsolidated soil and sediment deposits are primarily confined to the stream valleys and corridors. The unconsolidated deposits appear to have the greatest thickness in the eastern and southern parts of the Site. Glacial deposits blanket the lower slopes of ridges and hills and consist of heterogeneous mixtures of silt, sand, and gravel with boulders, typical of a ground moraine. The stream deposits are observed within the floodplains of the creeks and swamps and consist of clay and silt with some sand and gravel. These stream deposits are thought to be primarily derived from reworking of the glacial sediments.

Bedrock in the valleys and other topographic low areas is generally covered by overburden, which consists of unconsolidated and reworked glacial deposits and weathered bedrock. In some areas, the overburden is overlain by excavated rock, mine tailings, fill soil, and refuse from historical mining activities and historical landfills.

3.6 Hydrogeology

Groundwater at the Site occurs in both overburden and bedrock, but only in overburden where it is sufficiently thick to be continually saturated, usually a thickness observed to be greater than 8 feet. Where saturated, the overburden defines an upper aquifer and fractured bedrock a lower, or deeper, aquifer. The transition from the overburden aquifer, where it is present, to the bedrock aquifer is marked by a weathered bedrock zone of variable thickness (ranging from 0 feet to approximately 20 feet). Data generated during the RI indicate that there is limited hydraulic communication between the overburden and bedrock aquifers beyond the immediate vicinity of the underground mine workings because of the poor vertical permeability and transmissivity of the crystalline bedrock.

Groundwater occurs in the overburden under unconfined, water table conditions in the PMP Area and the OCDA. Although saturated overburden has not been encountered in the CMP Area because of insufficient overburden thickness, groundwater occurs in the bedrock aquifer beneath the entire Site, including within the CMP Area. The overburden aquifer is monitored in two zones, the upper water table and the lower, or deeper, overburden. The bedrock aquifer is monitored in multiple zones ranging from tens of feet in depth to approximately 500 feet bgs. Based on monitoring well yield during the more than 25 years of groundwater sampling at the Site, the hydraulic conductivity of the overburden aquifer is low to moderate and is low to very low in the bedrock aquifer.

In the PMP and CMP Areas, the abandoned underground mine workings have filled with groundwater and, therefore, represent significant storage of groundwater with the volumes of stored water estimated at 213,000,000 gallons and 49,000,000 gallons, respectively (Getz 1965). Based on the very low historical mine dewatering rates (less than 54 and 33 gpm, for the PMP and CMP Areas, respectively) and low to very low monitoring well yields during purging and sampling, the significant storage of groundwater within the abandoned mine workings does not appear to contribute to or increase the overall local hydraulic transmissivity, or groundwater movement, within the massive crystalline bedrock. Moreover, this large volume of groundwater storage and lack of yield from the area-specific monitoring wells indicates that fractures within the crystalline bedrock have very limited transmissivity and/or connectivity. The historical image to the right, of former mine workings, shows the massiveness of the rock and mine tunnels and illustrates that the tunnels are dry and the bedrock is not visibly fractured. The depth to groundwater in the overburden fluctuates seasonally and is typically deeper during dryer summer months with some wells being dry, or nearly dry, during drought conditions.

Historical photo of mine workings.

The direction of groundwater flow in both the overburden and bedrock aquifers is generally to the southeast. Groundwater ultimately discharges to streams, creating base flow in the perennial streams. As shown on Figure 2, surface water within the streams ultimately discharges into the

Wanaque Reservoir, located approximately 1 mile from the confluence of Park Brook, North Brook, Mine Brook, and Ringwood Creek (WCC 1988).

Although groundwater at the Site is classified as Class IIA, a potential potable water source by NJDEP, groundwater at the Site is *not* used as a potable water source, and drinking water for the nearby residents is provided by four water production wells maintained by the Borough of Ringwood located more than a mile from the Site in a completely different watershed.

3.7 Demography and Land Use

3.7.1 Demography

The United States Census Bureau reports that, in 2000, the Borough of Ringwood had a total population of 866 people living within 1 mile of the Site (209 total housing units). Approximately 200 people are believed to live in the 48 residences within the Site boundaries. According to the United States Census Bureau, 87 children under the age of 6 (10 percent of the population), 168 females between the ages of 15 and 44 (19.4 percent of the population), and 103 adults over the age of 65 (11.9 percent of the population) comprise the sensitive population within 1 mile of the Site.

Residential properties located within and near the Site consist primarily of single-family dwellings. Lot sizes are typically less than 0.5 acre, and there is substantial open space at the Site. Demographically, the Site area is considered sparsely populated.

There are no hospitals within 1 mile of the Site. There is one school within the 1-mile Site radius: the Eleanor Hewitt School (local elementary – 4th and 5th grades) located southeast of the Site on Sloatsburg Road. There is a private school, the Ringwood Christian School (K through 8th grade), located approximately 1.2 miles southeast of the Site on Carletondale Road.

3.7.2 Land Use

Current land use at the Site (excluding the embedded residential parcels) includes the Borough of Ringwood facilities (Department of Public Works yard and Recycling Center), State of New Jersey parkland (Ringwood Manor section of Ringwood State Park), utility corridors (PSE&G and Orange and Rockland Electric Company) that include a power substation, and open space (Borough of Ringwood property). Future development of open space at the Site is not considered likely because of conservation zoning, the presence of unbuildable slopes and wetlands, former landfills, extensive mine tailings deposits, and potential physical mine hazards (former pits and shafts).

Public drinking water is supplied to residents in the Borough of Ringwood from well fields located within a different watershed approximately 2 miles southeast of the Site. A secondary source of public drinking water is supplied from the Wanaque Reservoir, located approximately 0.5 mile southeast of the southernmost boundary of the Site. Groundwater and surface water are not used for potable purposes, and future use is unlikely given the high naturally occurring hardness, including elevated iron and manganese concentrations found in groundwater in historically mined areas, as well as at upgradient, background well locations. Low groundwater volumes and yield of the overburden and bedrock aquifers at the Site also contribute to the unlikelihood of development of the aquifers beneath the Site as potable water sources.

Paved roads at the Site are traveled by residents, mail carriers, delivery trucks, garbage and refuse haulers, utility workers, and visitors. The Recycling Center is open to the public on Wednesdays. Utility workers are periodically onsite to clear brush in the utility corridors and to perform maintenance on the power transmission towers and at the substation.

Known recreational uses of the land include hiking in Ringwood State Park, hunting, and riding all-terrain vehicles. Although there is a pond at the PMP Area, a water-filled former concrete fire-water reservoir, and several ponds created by beaver dams, fishing has not been observed. Swimming also appears to be an unlikely activity given the presence of dead tree snags, tree stumps, and/or debris in these areas, and/or inaccessibility due to the presence of heavy vegetation during the warmer months.

Areas of the Site where removal actions have occurred and the former landfill areas (PMP, CMP, and OCDA) are typically inaccessible during warmer months because of heavy vegetation at ground level (shrubs, vines, and briars). Restoration of these areas in the future will result in similar re-vegetation. Areas of sedimentation at the Site are typically inaccessible because of ponded water or swampy ground.

3.8 Ecology

The Site includes both wetland (along the stream corridors) and upland habitats. Historically, the Site area has been logged, in part to allow for mining operations. Ground surfaces at the Site are characterized by dense leaf litter, downed tree branches, and cobble- to boulder-sized rocks. Current vegetation at the Site is primarily what has grown naturally over the past 50 years.

Tree species present at the Site include red and white oak, chestnut oak, tulip poplar, black and yellow birch, American beech, sugar maple, green and white ash, eastern cottonwood, slippery elm, and sassafras. The present composition of mature trees that are 50 to 60 feet high with a closed canopy is dominated by tulip poplar, black and yellow birch, American beech, sugar maple, chestnut oak, white oak, and red oak. The understory is composed of trees of the same species listed above, and includes ironwood, serviceberry, and sassafras.

The shrub layer is composed of staghorn sumac, multiflora rose, wineberry, autumn olive, black raspberry, winged euonymus, buckhorn, witch hazel, spicebush, and maple leaf viburnum. The herbaceous layer is composed of succession species, including deer-tongue panicum, pokeberry, garlic mustard, joe-pye-weed, bracken fern, goldenrods, mullein, and a number of other grass species. Poison ivy, fox grape, Virginia creeper, mile-a minute, and Asiatic bittersweet are major woody vine species.

Wetlands vegetation consists of skunk cabbage, jewelweed, cinnamon fern, Christmas fern, sensitive fern, tear-thumb, and fringed loosestrife. Additional shrub species include sweet pepperbush, winterberry, and multiflora rose. Much of the shrub vegetation appears to have indications of heavy browsing by deer, especially the fringed loosestrife and jewelweed.

4. Remedial Investigation Summary

This section summarizes the scope of the RI activities conducted between 2005 and 2014 to evaluate groundwater and surface water quality at the Site. Additional activities to supplement groundwater and surface water data, including sediment investigations, a forensic analysis of Peters Mine Shaft, human population survey work, and ecological assessment are also described in this section. Finally, an analysis of geological investigations was conducted as part of the ongoing groundwater investigation work at the Site to support the evaluation of nature and extent of constituents at the Site.

The RI activities were performed in accordance with the respective USEPA-approved Work Plans described in Section 1 and in accordance with the project-specific Quality Assurance Project Plan (QAPP; ARCADIS 2004b). The completed activities described in this section include:

- Monitoring well installation and groundwater sampling and analysis
- Surface water sampling and analysis
- Groundwater flow and connectivity evaluation
    - Environmental tracer study
    - Flow characterization
    - Surface water measuring stations and rain gauge installation
    - Pressure transducer study
    - Stable isotope probing and Bio-Trap® investigation
- Sediment investigation
- Forensic analysis of Peters Mine Shaft
- Human population survey
- Ecological investigation
- Geologic investigation evaluation

Results of these investigations are presented in Sections 5 and 6 and are supported by tables, figures, and appendices as referenced.

4.1 Groundwater Investigations

4.1.1 Monitoring Well Location and Installation

Twenty-four monitoring wells were installed at the Site as part of investigation activities conducted between 1984 and 1991. The wells were installed upgradient and downgradient of the PMP Area, CMP Area, and OCDA, and at locations where paint waste had been removed for off-site disposal by Ford. Supplemental monitoring wells were installed between 2006 and 2014 as part of groundwater investigation activities conducted to complete groundwater flow and quality characterizations within the three ACs, as described in the sections below. Monitoring well construction details are provided in Table 1, and monitoring well construction logs are included as Appendix A.

The constituents reported in groundwater at the Site are typically very low in concentration (

typically less than 10 micrograms per liter [µg/L]) and are detected infrequently and sporadically; therefore, analytical results are sensitive to artifacts potentially being introduced during packer testing or groundwater sampling. Prior experience has shown that various materials used during packer testing could introduce low concentrations of VOCs and/or phthalates.

Following installation, the monitoring wells were developed with a submersible pump until the discharged water was nearly sediment-free, or for 30 minutes, whichever occurred first. Development water was contained in fractionation tanks for disposal through the on-site portable treatment system. The well casing elevations were surveyed by a New Jersey-licensed surveyor.

<u>Peters Mine Pit Area</u>

In the PMP Area, monitoring wells were installed in the overburden and bedrock to support the characterization of groundwater flow and quality in this area. Overburden monitoring wells OB-19, OB-20A, OB-20B, and OB-21 and bedrock wells RW-5, RW-6, RW-7, and RW-11 were installed in and around the PMP Area to characterize groundwater flow and quality and to evaluate the relationship between materials within the pit and groundwater quality in the overburden and bedrock (Figure 4). In addition, overburden monitoring well SC-01 was constructed in rotosonic boring SC-01 to characterize groundwater quality within the pit and downgradient of both the pit and the PM Air Shaft in the overburden and bedrock aquifers.

At the request of USEPA and NJDEP, additional wells were installed during the RI to provide additional groundwater flow and quality delineation, including overburden wells OB-27 and OB-30A, OB-30B, and OB-30C and bedrock monitoring wells RW-13S, RW-13D (100-120), and RW-13 (150-170). Downgradient bedrock wells RW-11 and RW-3D were installed at locations approved in advance by USEPA following multiple discussions and an on-site inspection. USEPA and NJDEP deemed these locations to be hydraulically downgradient of groundwater within the bedrock from the PM Air Shaft location, and these two wells were installed in response to USEPA's request to determine whether constituents reported in the PM Air Shaft groundwater (e.g., benzene) have migrated beyond the air shaft. Data were collected from these wells to further characterize the downgradient extent of any constituents in groundwater downgradient of the PMP and/or PM Air Shaft, respectively, and to provide wells for future groundwater monitoring.

Table 2 below provides installation details for these wells. The locations of these wells are shown on Figure 6.

Table 2 – Well Installation Details for PMP Area

Overburden Wells in the PMP Area	
Well IDs	Details
OB-19 OB-20A OB-20B OB-21	Installed downgradient of the former limits of the PMP. Soil borings advanced to the top of bedrock to characterize overburden thickness. Monitoring wells constructed with a 2-inch inside-diameter Schedule 40 polyvinyl chloride (PVC) riser and screen in accordance with NJDEP guidelines.
OB-27 OB-30A OB-30B OB-30C	Installed further downgradient of OB-19 through OB-21 pursuant to USEPA Comment Letter (USEPA 2011). Soil borings advanced to the top of bedrock to characterize overburden thickness. Monitoring wells constructed with a 2-inch inside-diameter Schedule 40 PVC riser and screen in accordance with NJDEP guidelines.
SC-01	Constructed in rotosonic boring SC-01 (angled). Target depth of the well screen was based on field evidence of potential impacts. Well constructed with a 2-inch inside-diameter Schedule 40 PVC riser and screen, with a screened length of 6.5 feet. Screened interval was from 64.4 to 70.9 feet bgs.

Bedrock Wells in the PMP Area	
Well IDs	Details
RW-5 RW-6 RW-7 RW-11	Initial well installations proposed to and approved by USEPA in 2007. Constructed with 2-inch-diameter PVC well casing installed with a slotted screen placed at the following intervals to complete the bedrock monitoring well network at the PMP: • **RW-5** 54 to 74 feet bgs (covers two bedrock water-bearing zones: RW-5A provides an upper bedrock monitoring point, and monitors groundwater quality at the same vertical interval as slanted well SC-01 in the pit, slotted from 64.4 to 70.9 feet bgs) and 99 to 119 feet bgs(monitors water quality and potentiometric head below the bottom of the pit). • **RW-6** 58 to 78 feet bgs (covers two bedrock water-bearing zones of very low to low yield – named RW-6A – provides an upper bedrock monitoring point and monitors groundwater at the same vertical interval as angled well SC-01) and 99 to119 feet bgs (monitors water quality and potentiometric head below the bottom of the pit). • **RW-7** 99 to 119 feet bgs (monitors upgradient groundwater quality and potentiometric head at a depth that corresponds to the bottom of the pit). Because no constituents have been reported above the Groundwater Quality Standard (GWQS) at any depth interval at this upgradient well location, this deeper interval was selected for background monitoring purposes. The lower intervals were installed as cased wells in the existing rock boreholes. The upper intervals were installed in new rock boreholes, which were paired with the corresponding existing locations. • **RW-11** The Zone Isolation Sampling Technology (ZIST™)[1] with multi-port/multi-level screens was chosen for site bedrock wells, including RW-11. The ZIST™ wells system dedicates pumps seated in PVC receptacles to purge and sample the isolated zones. The simultaneous control unit allows purging and sampling of different zones at the same time. Targeted zones at RW-11 include the intervals of 236 to 241 and 262 to 267 feet bgs.
RW-3D	• ZIST™ with multi-port/multi-level screens were installed within the RW-3D boreholes, and the well was screened at the following intervals: 155 to 160 feet bgs (RW-3DS) and 175 to180 feet bgs (RW-3DD)
RW-13	• There are a total of three monitoring wells associated with the downgradient RW-13 bedrock well cluster. Specifically, RW-13S is a shallow bedrock monitoring well which is screened from 71 to 91 feet bgs (2-inch PVC) • ZIST™ with multi-port/multi-level screens were installed within the RW-13D borehole and the well was screened at the following intervals: 100 to 120 feet bgs [RW-13D(100-120)] and 150 to170 feet bgs [RW-13D(150-170)]

[1] The ZIST™ system allows for monitoring groundwater at multiple discrete and isolated bedrock intervals. The well screen is isolated and is docked with the pumps to draw samples only from the well screen.

Cannon Mine Pit Area

Monitoring wells were installed in the CMP Area to characterize groundwater quality in the vicinity of the pit and flow direction within fill materials and bedrock. In addition, following completion of the rotosonic borings within the CMP fill materials, a monitoring well was constructed at boring location S-5 and the well was designated SC-02. This monitoring well was installed to assess the groundwater quality and water table elevation within the pit. Table 3 below provides installation details for CMP Area monitoring wells and the locations of these wells are shown on Figure 7.

Table 3 – Well Installation Details for CMP Area

Bedrock Wells in the CMP Area	
Well IDs	Details
RW-8 RW-9 RW-10	Advanced around the perimeter of the CMP in December 2007 Monitoring well boreholes were then logged with downhole geophysical tools in March 2008 to identify potential water-bearing fractures in the bedrock.
SC-02	Constructed at rotosonic boring location S-5. Constructed with a 20-foot screen that installed from 47 to 67 feet bgs based on the groundwater level observed during drilling (see Table 1). The screen is positioned below the solid waste material starting in the sand/silt fill zone and extending approximately 17 feet into the rock rubble zone.
RW-2 RW-8 RW-8A RW-9 RW-9A RW-10 RW-10A	Installed the ZIST^{TM} system in these wells in April 2010. Well construction logs were provided in Appendix B of the PMP RIR (ARCADIS 2012c).

O'Connor Disposal Area

Groundwater quality in the vicinity of the OCDA was initially investigated as part of the 1984 to 1988 RI with the installation of three groundwater monitoring wells screened within the unconsolidated overburden deposits. These wells range in depth from 20 to 63 feet bgs, and are referred to as wells OB-9, OB-14A, and OB-14B.

Between 2005 and 2012, eight additional wells were installed within and around the OCDA to verify groundwater flow and quality and to establish the relationship between the nature of the waste materials located within the OCDA and the potential effect on groundwater quality. All 11 monitoring wells at the Site remain active in the Site-related groundwater monitoring program, with the exception of well OB-9, which was damaged and can no longer be sampled. Table 4 below provides installation details for OCDA monitoring wells and the locations of these wells are shown on Figure 3.

Table 4 – Well Installation Details for OCDA

Overburden Wells in the OCDA	
Well IDs	Details
OB-14A OB-9 OB-14B	OB-14A was completed to a depth of 20 feet bgs and screened across fill material within the OCDA. OB-9 and OB-14B completed to depths of 51 to 61 feet bgs and 25 to 35 feet bgs, respectively, and were screened within the native soil.
OB-16 OB-17 OB-18	Installed to monitor groundwater in the vicinity of four magnetic area anomalies identified within the OCDA during a geophysical investigation. These wells were screened in the shallow overburden groundwater table at depths ranging from 13 to 20 feet bgs.
OB-22 OB-23 OB-24 OB-25 OB-28	Installed to better evaluate the groundwater regime within and surrounding the OCDA. OB-22 and OB-24 were positioned to provide monitoring points along the anticipated downgradient southern edge of the OCDA and along the northeastern edge anticipated to be downgradient of the central sections of the OCDA. OB-23 was installed within the central part of the former OCDA and was screened within the overburden beneath the fill materials at this location. OB-25 was installed to the west and north of the OCDA, across Peters Mine Road by Sheehan Drive, to assess upgradient groundwater quality and for verification of the groundwater flow gradient.

<u>Sentinel Off-Site Locations</u>

In a Comment Letter dated July 14, 2011**,** USEPA requested that downgradient sentinel wells be installed to define regional/valley-wide groundwater flow (USEPA 2011). Based on this request, bedrock well RW-12 and overburden monitoring well OB-29 were installed downgradient and offsite to the southeast in the adjacent Ringwood State Park (Figure 3).

Packer testing was conducted at bedrock well RW-12 per the April 9, 2012 RW-12 Packer Testing Work Plan. A downhole geophysical survey was performed at borehole RW-12 by Geophysical Applications, Inc. in December 2011. The well RW-12 geophysical log is included in Appendix A.

Competent bedrock (gneiss) was encountered at a depth of approximately 38 feet bgs, 6-inch-diameter steel casing was set to approximately 50 feet bgs, and the RW-12 bedrock well was drilled to a total depth of approximately 150 feet bgs. The packer testing and sampling of fractures in bedrock well RW-12 was conducted using dual-packer system packer testing at the following intervals:

- 50 to 70 feet bgs
- 96 to 116 feet bgs
- 125 to 148 feet bgs

Based on sustained groundwater yields observed and packer testing analytical results, multi-port monitoring wells were constructed in the RW-12 open rock borehole, with screened intervals at 55 to 65 feet bgs and 130 to 140 feet bgs, constructed utilizing the ZIST™ multi-port/multi-level monitoring system.

4.2 Summary of Groundwater Sampling Events (2004 to 2014)

ARCADIS has performed groundwater sampling and monitored groundwater elevations at up to 55 monitoring wells located at the Site between 2004 and 2014 in accordance with the USEPA-approved Post-EMP Work Plan (ARCADIS 2004a) and Groundwater Sampling Work Plan (ARCADIS 2006a). Sampling was conducted on a semi-annual basis from 2004 through 2009 and on an annual basis from 2010 through 2014 and has resulted in the collection of over 560 groundwater samples from the Site.

This section summarizes groundwater sampling conducted at the Site between 2004 and 2014. A complete summary of the scope and sampling results of each sampling event have been provided in groundwater technical memoranda submitted between 2006 and 2012 (ARCADIS 2007a, 2008a, 2008b, 2009a, 2009b, 2010a, 2010b and 2011), which are provided in Appendix B of this RIR. Technical memoranda were not submitted for 2012, 2013, or 2014 data, rather these data are presented in this RIR. The analytical results of groundwater sampling for 2004 through 2014 are discussed in Section 5 of this document.

Groundwater samples were collected from each well using the groundwater sampling and analytical procedures documented in the project-specific QAPP (ARCADIS 2004b) approved by USEPA. Table 5 summarizes the RI monitoring and analytical program. As specified in the Post-EMP Work

Plan, each sample was analyzed for Target Analyte List (TAL) inorganic compounds, Target Compound List (TCL) organic constituents, and chloride, sulfate, carbonate and bicarbonate, nitrate, and phosphate.[2] The samples were analyzed at Accutest Laboratories in Dayton, New Jersey, using the following SW-846 methodology, as described in the QAPP:

Table 6 – Analytical Methods for Groundwater Samples

Analytes	Method
TCL VOCs	USEPA Method 8260B
TCL SVOCs	USEPA Method 8270C
TAL Metals	USEPA Methods 6010B/7470A
Pesticides/PCBs	USEPA Methods 8081A/8082
Cyanides	USEPA Method 9012A

Beginning in April 2007 and for all subsequent sampling events, USEPA approved the deletion of pesticides from the analytical protocol because these compounds have not been detected in groundwater at the Site. Quality control samples were obtained in accordance with NJDEP and the project-specific QAPP.

Both unfiltered (total metal) groundwater samples and filtered (dissolved metal) samples were analyzed for TAL metals to compare the results, as necessary, to evaluate the potential contribution of elevated particulate levels in groundwater prior to filtering on the reported concentration of metals in the groundwater sample because elevated particulates can result in a “bias high” for various metals. The filtered (dissolved metal) data are also necessary to evaluate any influence of geochemical conditions (especially oxidation-reduction and pH) on the reported concentration of both total and dissolved metals to aid in the proper technical interpretation of the groundwater analytical data with respect to characterization of actual groundwater quality.

In addition, an alternate analytical method for arsenic (USEPA Method 7062) was used for comparison to the results reported using USEPA Method 6010C for purposes of evaluation of the potential interference from REEs. This comparative evaluation was conducted during the September 2014 sampling event at the following select well locations: CMP bedrock well RW-10, PMP overburden wells OB-11R and OB-27, PMP bedrock wells RW-5A and RW-3DD, and OCDA overburden wells OB-14A and OB-16. The comparative evaluation is discussed in detail in Section 4.6.6.

All laboratory analytical results were reviewed and validated by ARCADIS in accordance with the QAPP. Validation qualifiers and comments were added to the data tables as appropriate. No data were invalidated.

Peters Mine Pit Area

As shown on Figure 3, the characterization of groundwater flow and quality within the PMP Area over the course of the RI has been accomplished through monitoring the following overburden wells:

OB-11R, OB-15B, OB-19, OB-20A, OB-20B, OB-21, OB-27, OB-30A, OB-30B, and OB-30C and the following bedrock wells: RW-4A, RW-4, RW-3, RW-3D, RW-3DD, RW-5, RW-6, RW-6A, RW-7, RW-11. RW-13S, and RW-13D. Monitoring well SC-01 is located and screened within the Peters Mine Pit.

Cannon Mine Pit Area

As shown on Figure 3, the characterization of groundwater flow and quality within the CMP Area over the course of the RI has been accomplished through monitoring the overburden well SC-2 located within the CMP and, because there is no saturated overburden elsewhere within the CMP Area, through the following bedrock wells: OB-2, OB-3, OB-4, OB-5, OB-12, OB-13, RW-8, RW-9, and RW-10.

O'Connor Disposal Area

As shown on Figure 3, the characterization of groundwater flow and quality within the OCDA over the course of the RI has been accomplished through monitoring the following overburden wells: OB-9, OB-14A, OB-14B, OB-16, OB-17, OB-18, OB-22, OB-23, OB-24, OB-25, and OB-28.

Downgradient Monitoring Well Locations

Monitoring wells located downgradient of the immediate PMP Area, CMP Area, and OCDA are also included in the Site-Related Groundwater monitoring program. The locations of these wells are described below and shown on Figure 3.

Well IDs	Location
OB-7	Adjacent to Peters Mine Road, which is downgradient of the PMP and OCDA

Well IDs	Location
OB-10 OB-29 RW-12	Off site and downgradient in the adjacent Ringwood State Park

Upgradient (Background) Monitoring Well Locations

Monitoring wells located upgradient of the PMP Area, and CMP Area, and OCDA are also included in the Site-Related Groundwater monitoring program. The locations of these wells are described below and shown on Figure 3.

Well IDs	Location
OB-1 RW-1 OB-25 OB-6	Upgradient of the CMP, OCDA
OB-8	Upgradient of the PMP. This well was abandoned in 2004.

4.3 Surface Water Investigations

A surface water sampling and analysis program was implemented from 2005 to 2012 to supplement the previous 20 years of surface water sampling results collected from 1984 through 2004. The 2005 to 2012 sampling program was implemented to assess surface water quality in the onsite streams (including the Mine Brook, Peters Mine Brook, Park Brook, and North Brook), the pond near the PMP, two seep locations, and areas where groundwater discharges to surface water as shown on Figure 3. Activities conducted as part of this program were in accordance with the Work Plan for the Stream Sediment/Surface Water Sampling Activities (ARCADIS 2005a), the 2005 AOC, and the Proposed Groundwater Sampling Modification comments provided by USEPA in 2011 (USEPA 2011). Note that surface water sampling was not conducted in 2013 or 2014 because USEPA agreed that it was not part of the work scope.

Surface water samples collected in 2005 were submitted for:

- TAL metals
- TCL
- VOCs
- SVOCs
- PCB
- Water chemistry parameters (including pH and hardness)

Subsequent samples collected in 2011 and 2012 also included analysis for:

- Alkalinity
- Chloride
- Cyanide
- Nitrate
- Nitrogen
- Nitrite
- Sulfate
- Total organic carbon (TOC)
- Total dissolved solids (TDS)

4.4 Sediment Pore Water Investigation (2014)

A sediment pore water investigation was performed in August through September 2014 in accordance with the USEPA-approved April 21, 2014 Proposed Surface Water and Sediment Pore Water Investigation Work Plan (ARCADIS 2014). The purpose of the study was to further characterize the groundwater flow pathways in the PMP and evaluate the potential discharge of groundwater and flux of VOCs through the sediment pore water beneath the bed of Park Brook. The evaluation included the collection of sediment pore water samples in Park Brook for benzene analysis and water level monitoring with transducers and stream gauges to further refine the CSM for the PMP Area. USEPA approved the work plan in their May 13, 2014 correspondence. Results of the sediment pore water investigation are presented in Section 5 of this RIR.

In order to provide a more detailed evaluation of the relationship between groundwater discharge and surface water recharge and/or discharge and the potential discharge of groundwater and any associated VOC flux through the sediment pore water beneath Park Brook, a total of seven piezometers were proposed to be installed into the bed of Park Brook. The locations were to supplement the three existing surface water measuring stations SW/SD-11, SW/SD-PAB-01, and SW/SD-12/PAB-01A, as shown in Figure 3. Passive diffusion bags (PDBs) were proposed to be installed at each of the locations to obtain samples for VOCs analysis.

The existing surface water measuring stations consist of land-based surveyed pins from which surface water levels can be measured with staff gauges. The tops of the stream gauges were also surveyed by a licensed New Jersey Surveyor. Synoptic surface water level measurements were collected twice per month between August and November 2014. Transducers were also placed in select monitoring wells along the subject stretch of Park Brook, including overburden wells OB-19, OB-20A and 20B, OB-21, OB-24, and OB-27 and bedrock wells RW-5, RW-5A, RW-3 (cluster), and RW-11S.

Based on field conditions encountered during piezometer installation, which included large boulders and cobbles, only one of the proposed locations (PZ-C) could be installed in accordance with the April 2014 Work Plan (ARCADIS 2014) as observed by NJDEP and USEPA field staff during the attempted installations. The PZ-C location is shown on Figure 3. Additional attempts at piezometer installation were made at several locations within Park Brook with refusal continually encountered due to the boulders and cobbles within the poorly sorted glacial deposits in these areas. Following discussions with NJDEP and USEPA, the decision was made to discontinue any further attempts at installing piezometers and the other proposed locations.

Piezometer PZ-C was set to a depth of 4 feet bgs and constructed with 2-inch diameter, Schedule 80 PVC with the bottom 12- inches consisting of 0.020 slotted casing in accordance with the USEPA-approved Work Plan. A 12-inch PDB pre-filled with laboratory grade deionized water was installed at the base of the piezometer. The PDB remained in place for 28 days prior to removal and was submitted for TCL VOCs analysis by USEPA Method 8260B.

Stainless steel direct point push samplers were also utilized in an attempt to collect sediment pore water samples at each of the locations where piezometer refusal was encountered. Specifically, location PZ-D was the only location where the push point sampler was able to reach the targeted depth of 4 feet bgs and a second pore water sample (designated PZ-D) was collected. Refusal was encountered at the remainder of locations due to subsurface obstructions by cobbles and boulders. Sediment pore water sample PZ-D was also submitted for TCL VOCs analysis by USEPA Method 8260B.

The TCL VOC analytical results of the sediment pore water sampling are discussed in Section 5.

4.5 Groundwater Flow and Connectivity Evaluation

A groundwater flow and connectivity evaluation was completed from April through August 2012 as part of supplemental groundwater investigation activities in accordance with the Proposed Supplemental Site-Related Groundwater Remedial Investigation Work Plan (ARCADIS 2012a). These activities were conducted to complete the characterization of groundwater with respect to flow pathways and connectivity between groundwater in the overburden and bedrock, as well as discharge to surface water and constituent migration pathways. The scope of work for the Supplemental RI was developed in response to correspondence and discussions between USEPA, NJDEP, and Ford regarding the performance of a tracer study in the vicinity of the PMP and the CMP, and as necessary to complete the RI of Site-related groundwater. USEPA approved the supplemental Work Plan in their August 15, 2012 correspondence. The methodology and results for the groundwater flow and connectivity evaluation are presented in Section 6.

4.6 Additional Supporting Investigations

Ford conducted a number of additional investigations at the Site to support source identification, characterization of nature and extent of constituents, and evaluate potential risks. These investigations included:

- Sediment investigations
- Surface soil investigation
- Human population survey
- Ecological investigation
- Forensic analysis of PM Shaft

4.6.1 Sediment Investigations

Sediment investigations were conducted in 2005 and 2011 in the four primary streams on Site, the PMP pond, and the PM Air Shaft. These investigations were conducted to evaluate the nature and quality of the sediments, the extent of any constituent impacts at the Site, and the presence of constituents of potential ecological concern (COPECs) in pond sediment.

4.6.1.1 *2005 Stream Sediment Sampling Program*

In conjunction with the surface water sampling program, a stream sediment sampling program was initiated in 2005 in accordance with the Work Plan for the Stream Sediment/Surface Water Sampling Activities (ARCADIS 2005a) and the 2005 AOC. The sediment sampling locations for each stream are shown on Figure 3.

Ten samples were collected from the upper 6 inches of sediment, and samples were tested for grain size, TAL metals, TCL, VOCs, SVOCs, PCBs, and TOC. Results from these samples were compared with NJDEP Freshwater Sediment Low-Effects Level (LEL) Criteria and Severe-Effects Level (SEL) Criteria. NJDEP LEL screening criteria are based on constituent concentrations that have been shown to cause an observed detrimental impact on macro-invertebrate species during a controlled study. These criteria generally serve as an indicator that further study may be warranted to evaluate potential impacts.

4.6.1.2 *Peters Mine Pit Pond Sediment Sampling*

Sediment samples were collected from the PMP Pond in May 2011 in accordance with the USEPA-approved Sediment Sampling Work Plan for the PMP Pond (ARCADIS 2011a). This sampling was conducted to evaluate the nature and quality of sediments within the pond and to assess whether COPECs were present within the pond sediments in association with the performance of the Screening Level Ecological Risk Assessment Report (SLERA) prepared for this area (ARCADIS 2011b).

Six sediment samples were collected from the base of the pond from the 0- to 6-inch depth interval and analyzed for TCL SVOCs, PCBs, TAL metals, TOC, and grain size. Samples for VOC analysis were collected from the base of the pond from the 6- to 12-inch depth interval using Encore® samplers (NJDEP 2005). Sediment sampling locations for the PMP Pond are shown on Figure 3.

Concentrations of COPECs were screened using NJDEP’s ecological screening levels for sediment, or ecologically based screening levels (EBSLs), in a manner similar to the method used in the PMP Area SLERA (ARCADIS 2011b). This screening was consistent with NJDEP’s Guidance for Sediment Quality Evaluations (NJDEP 2011).

Multiple EBSLs were used for comparison purposes to provide context and to identify potential adverse environmental effects, such as effects on plant and animal populations and communities. NJDEP was the primary source of the EBSLs used in this evaluation, as well as the secondary sources listed below:

- NJDEP sediment freshwater criteria for LEL. The LEL represents the concentration at which adverse effects may begin to be seen in benthic organisms.
- USEPA Region 5 ecological screening levels for sediment if NJDEP LEL values are unavailable.
- National Oceanic and Atmospheric Administration Screening Quick Reference Table for sediment.

If available, the LEL sediment screening values were used because they typically represent the most-conservative screening value for a given COPEC. Screening with SELs was also conducted if a COPEC exceeded the LEL.

4.6.1.3 *Peters Mine Air Shaft Sediment Sampling*

A sediment sample was collected from the PM Air Shaft on October 20, 2011 in accordance with the USEPA-approved PM Air Shaft Sediment Sampling Work Plan (ARCADIS 2011c) to assess whether or not the sediment serves as a potential source of benzene and/or any other constituents reported in groundwater samples collected within the air shaft, including bis(2-ethylhexyl)phthalate and lead The original work scope called for the collection of multiple samples from the base of the PM Air Shaft. However, the non-cohesive sediment in addition to the presence of abandoned mine equipment, tree debris, and other obstructions made it difficult to collect the sediment.

After repeated efforts to obtain a sample, a sediment sample with sufficient volume to fill the sample containers was successfully collected from the base of the PM Air Shaft where it intersects the inclined mine shaft. This sediment sample represents the 0- to 18-inch depth interval within the sediment at the base of the Air Shaft. In accordance with the Work Plan, the sediment was analyzed for TCL VOCs, SVOCs, PCBs, and TAL metals.

The sediment analytical results are further discussed in Section 5 of this RIR. Concentrations of COPECs were screened using NJDEP's ecological screening levels for sediment, or EBSLs, in a manner similar to the method used in the PMP Area SLERA (ARCADIS 2011b). This screening was consistent with the NJDEP's Guidance for Sediment Quality Evaluations (NJDEP 2011).

Multiple EBSLs were used to provide context and to identify potential adverse environmental effects, such as effects on plant and animal populations and communities. NJDEP was the primary source of the EBSLs used in this evaluation, together with secondary sources (see Section 4.5.1.2).

If available, the LEL sediment screening values were used because they typically represent the most conservative screening value for a given COPEC. Screening with SELs was also conducted if a COPEC exceeded the LEL.

4.6.2 Forensic Analysis of Peters Mine Shaft

Additional analysis was completed to evaluate potential sources of benzene at the base of the PM Air Shaft and to evaluate and further characterize the physical and chemical make-up of the sediment. The results of this analysis are presented in Section 5.3.

4.6.3 Soil and Vadose Zone Investigations

Surface soil samples in the CMP Area were collected on October 23, 2007 to characterize surface soil quality. Sampling locations and the analytical results are provided in the CMP RIR (ARCADIS 2013b). Surface soil sampling logs are also included in Appendix B of the CMP RIR. Ten surface soil samples were collected and analyzed for TCL VOCs, SVOCs, PCBs, TAL metals, and total petroleum hydrocarbons. Quality assurance/quality control samples, including one duplicate sample, one trip, and one field blank, were also collected. Soil samples were obtained from a depth of 0 and 6 inches bgs for non-volatile compounds and from 18 and 24 inches for VOCs. Note that soil and vadose zone investigations for the PMP Are and OCDA were performed in conjunction with source area investigations in these areas as discussed in Section 4.6.

4.6.4 Human Population Surveys

Baseline Human Health Risk Assessments (BHHRAs) for the PMP Area, CMP Area, and OCDA were submitted to USEPA under separate covers in March and June 2012, as a requirement established in the Statement of Work and were approved by the USEPA in September 2013. The BHHRA for Site-related groundwater will be provided under separate cover. The BHHRA is an assessment that includes potential cancer risks and non-cancer hazards to human health, which are identified and characterized in accordance with USEPA guidance's, including, but not limited to, the Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (USEPA 1989).

This assessment also includes a description of the representative constituents and associated concentrations in site media (including soil, sediment, surface water, game tissue, and plant tissue) that have been determined by using all currently available media-specific analytical data generated during the Supplemental Investigation.

4.6.5 Ecological Investigations

Revised SLERAs for the PMP Area, CMP Area, and OCDA were submitted to USEPA under separate covers in January, March, and June 2012 (ARCADIS 2012d, 2012e, 2012f), respectively. The SLERAs used conservative exposure estimates to compare maximum constituent concentrations in each environmental medium to the appropriate conservative ecotoxicity screening values.

As detailed in the revised SLERA for the PMP Area, data from the PMP RI for soil, surface water, groundwater, and sediment indicate a potentially complete exposure pathway with respect to the American Robin. Upon USEPA review (March 7, 2012), it was determined that a full updated Baseline Ecological Risk Assessment (BERA) was required. A draft BERA was conducted and the draft report submitted to USEPA on May 29, 2012 (ARCADIS 2012g).

As presented within the draft SLERA for the CMP Area, data generated from the CMP RI for soil, surface water, and groundwater indicate no complete ecological exposure pathway in the CMP Area, or that concentrations of constituents detected were not anticipated to result in any adverse ecological impact. Based on the information in the SLERA, a final BERA was submitted to USEPA on July 23, 2013 (ARCADIS 2013a) and approved by USEPA on July 2, 2013.

A SLERA for the OCDA was submitted to the USEPA under separate cover. The SLERA provided a comparison of the maximum constituent concentrations in each medium of concern to appropriate conservative ecotoxicity screening values, and conservative exposure estimates will be used. Based on the information in the SLERA, a final BERA was submitted to USEPA on July 23, 2013 (ARCADIS 2013d) and approved by USEPA on August 12, 2013.

4.6.6 Arsenic Evaluation

During the most recent groundwater sampling event conducted at the Site (September 2014), ARCADIS analyzed a select group of groundwater samples for arsenic using two USEPA test methods to evaluate whether rare earth elements (REEs) were potentially causing false positives in the reported groundwater analytical test results. The typical method used at the Site to analyze for TAL metals is SW846 USEPA Method 6010C. An alternate method is USEPA Method 7062. This alternate method is not susceptible to interference from REEs and therefore will not yield false positive results. This method is also more sensitive to arsenic and therefore a more precise analysis (USEPA 1999). As discussed in Section 4.6.6.1 below, the results of this comparative supplemental analysis indicate that REEs are potentially present in overburden groundwater and, as such, the historical arsenic concentrations reported using USEPA Method 6010C may be biased high

The following section documents this supplemental comparative groundwater analytical evaluation and presents the results of the side-by-side analyses.

4.6.6.1 *Background*

As a result of work conducted by ARCADIS at a USEPA-led site in Region 4, ARCADIS observed an issue with standard USEPA Methods SW846 6010 and 6020. At this site, the data indicated false-positive results for reported arsenic concentrations in groundwater and soil. REEs introduce spectral and mass/charge interferences in these methods that are not well-known at this time and are not easily identified and corrected for (Nakano and Shikamori 2003; R. Thomas 2002; Hu, Gao et al. 2005). The REEs may be present in groundwater and soil (or mine tailings) if an aquifer is enriched in these naturally occurring elements. The naturally occurring elements are often present in phosphate minerals and ores, such as those that occur at the Site where REEs are present in the accessory mineral apatite found with the iron ore bodies. REEs are also associated with fertilizer processing residues and fly ash and, if REE-containing minerals are undergoing dissolution, USEPA Method 7062 (a gaseous hydride atomic adsorption method) provides a more specific quantification of arsenic and is less prone to REE interferences (USEPA 1999; Nakano and Shikamori 2003; R. Thomas 2002; Hu Gao et al. 2005).

As part of this supplemental evaluation, a total of seven monitoring wells (including four overburden wells and three bedrock wells) in which the groundwater analytical results have typically reported arsenic at concentrations above its 3 µg/L GWQS were selected to have the collected groundwater samples analyzed for arsenic (total and filtered) using both USEPA Methods 6010C and 7062. The selected wells are located such that groundwater quality could be assessed in all three land ACs as follows: CMP bedrock well RW-10, PMP overburden wells OB-11R and OB-27, PMP bedrock wells RW-5A and RW-3DD, and OCDA overburden wells OB-14A and OB-16. The well locations are shown on Figure 3.

The analytical results for arsenic from this assessment are presented in Table 7, and the laboratory report is provided in Appendix C. Table 7 also summarizes the corresponding alkalinity, dissolved (filtered) iron concentrations, and field geochemical parameters (pH, turbidity, oxygen-reduction potential) for the groundwater samples that were also utilized in this supplemental evaluation.

4.6.6.2 *Findings*

Several observations are apparent from evaluation of the data set summarized in Table 7:

1. The reported total arsenic concentrations using USEPA Method 7062 are consistently higher than those reported via USEPA Method 6010C, reflecting the greater sensitivity of Method 7062 with respect to arsenic.

2. The reported dissolved (filtered) arsenic concentrations using USEPA Method 7062 indicate that dissolved (filtered) arsenic is either not present (i.e., non-detect) or is present at trace levels in groundwater at overburden well locations indicating that USEPA Method 6010C analytical results biased high and reflect predominantly false positive concentrations in the reported arsenic values.

3. USEPA Method 7062 arsenic analytical results show that total and dissolved arsenic are essentially equivalent in two of the three bedrock samples (PMP Area well RW-3DD and CMP Area well RW-10) indicating that the majority of the reported arsenic concentrations in groundwater within the deep bedrock is in the dissolved form which is consistent with the low sample turbidity at these locations.

4. The elevated groundwater sample turbidity is likely a contributing factor in the reported total arsenic in groundwater at PMP Area overburden well OB-27 and at PMP bedrock well RW-5A where turbidity values of 44.7 and 21.7 NTUs were reported, respectively

As shown on Figure 3, OCDA Area overburden wells OB-14A and OB-16 are located near the former “slime” tailings pond associated with historical mining activities within the PMP Area. Overburden well OB-11R is located upgradient of the OCDA and a coarse tailings disposal area and downgradient of the PMP Area. Overburden well OB-27 is located upgradient of the OCDA and downgradient of the PMP Area. Bedrock well RW-5A is located adjacent to the PMP Air Shaft and bedrock well RW-3DD is located downgradient of the PMP Area. Bedrock well RW-10 is located adjacent to the Hard Mine pit. Based on the geology of the Site, the data indicate that bedrock wells located in the vicinity of the mine pits are also in close proximity to residual ore bodies and alteration zones. Bedrock well RW-5A, located adjacent to the PMP, is also located near a subsurface deposit of mine tailings within the PMP.

Because arsenic and REEs are both present in the mineral apatite and not in different mineral assemblages (as known from electron microscopy and laser ablation studies), the data suggest that it is unlikely that preferential dissolution is a factor. REEs, if available, will dissolve in neutral/alkaline pH in the presence or relatively high alkalinity, geochemically iron-reducing conditions, and/or the presence of dissolved organic carbon (soluble REE-organic complexes can form). At the Site, the groundwater data for the OCDA and PMP show that two conditions that can result in dissolved REEs are present, specifically elevated alkalinity (i.e., very hard water) and high dissolved iron. The presence of total arsenic in the groundwater at these locations but the lack of dissolved (filtered) arsenic via USEPA Method 7062 indicates that the arsenic concentrations reported in groundwater in overburden in these areas reflect particle-bound arsenic.

The data indicate that arsenic reported in groundwater in the deeper bedrock wells in the PMP and CMP Areas where the results of the RI document that the vertical groundwater flow gradients are upward is in a dissolved form and is most likely naturally occurring given the location of these bedrock wells near former underground mine workings.

4.6.6.3 *Conclusions*

Analytical results from groundwater samples analyzed by USEPA Method 7062 show that dissolved (filtered) arsenic was not detected in groundwater at the overburden wells selected for the evaluation or was only detected at trace concentrations below the arsenic GWQS of 3 µg/L. The results of the supplemental evaluation indicate that arsenic analytical results reported via USEPA Method 6010C are biased high likely due to interference from REEs as evidenced by the comparison to the analytical results generated using the more sensitive USEPA Method 7062. The results indicate that concentrations of arsenic reported in bedrock groundwater are not affected by the bias high due to REE interference with the exception of groundwater at PMP Area shallow bedrock well location RW-5A where groundwater contains higher dissolved iron concentrations although sample turbidity could also be a factor.

4.7 Summary of Findings - Geological Investigations

This section provides a summary of the soil, fill, and bedrock characteristics determined based on the data collected during the many investigation phases of the project, and is provided herein for reference purposes, as well as to document the completeness of the Site investigation. Test pits, trenching, and soil borings were completed to identify the geology and the types of soil and fill materials and fill layering characteristics, and to collect samples for laboratory analysis to characterize soil and fill quality. Borings were also completed to characterize bedrock and to identify and investigate water-bearing fractures and voids in the PMP Area and the CMP Area, as well as at select offsite areas downgradient of the Site. Extensive RI activities were conducted in the PMP Area, CMP Area, and OCDA to evaluate the physical characteristics (e.g., the extent and quality of soil and fill material) of these areas and identify whether Site-related constituents were present in these areas, which would assist with characterizing the sources of these constituents. Investigation activities in these three areas included excavating test pits, advancing soil borings, and collecting soil samples for laboratory analyses. Details of the investigations are provided in the RIRs for each area: Remedial Investigation Report for the Peters Mine Pit Area (PMP RIR), CMP RIR, and OCDA RIR (ARCADIS 2012c, 2013b, and 2013c, respectively).

4.7.1 Fill Material Characterization

Fill material characterization activities were performed to identify the types of fill materials in the three ACs and the fill layering characteristics of the fill materials. The results of the fill material investigation activities are summarized below and discussed in detail in the area-specific RIRs (ARCADIS 2012c, 2013b, and 2013c).

4.7.1.1 *Peters Mine Pit Area*

<u>Test Trench Excavations</u> – Two test trenches were excavated in 2006 to characterize fill materials on the perimeter of the PMP (Figure 4). The waste materials consisted of various debris mixed with fill material, drum remnants, and limited pockets of paint waste.

<u>Test Pit Excavations</u> – Seven test pits were excavated in 2006 to confirm the limits of fill surrounding the PMP (Figure 4). Fill materials encountered within the test pits included debris mixed with fill material, drums remnants, and limited paint waste pieces.

In January 2011, ARCADIS removed paint waste from the following areas, which were identified during the 2006 investigations: TT-01 and TT-02 and test pits TP-01 and TP-09. Removed material was disposed offsite at approved facilities. In April 2011, an additional area of paint waste was identified north of the PMP and is referred to as Waste Removal Area 13 (SR-13). Ford voluntarily excavated the paint waste from this area in early 2012, and disposed the material offsite at approved facilities. The results of the investigation and remedial action in this area were documented in a Technical Memorandum that was submitted to the agencies under separate cover.

<u>Angled Directional Boring Installations</u> – Four borings were advanced to the sidewall or base of the PMP in March and April 2006 (Figure 4). The boring logs, provided in Appendix D of the PMP RIR (ARCADIS 2012c), showed that the PMP fill consists mainly of intermixed soils, debris, and mine tailings underlain by mine tailings.

A soil/solid waste sample was collected from each 10-foot core recovered during the advancement of the four borings. The samples were collected for analysis based on visual appearance and were screened for VOCs using a photoionization detector. Analytical results were compared to the NJDEP Impact to Groundwater Default Soil Screening Levels (IGWDSSL). These results are discussed in Section 5, as well as in the in the PMP RIR (ARCADIS 2012c). Input values for the calculation of site-specific IGWDSSL were presented in Appendix C of the PMP RIR.

4.7.1.2 *Cannon Mine Pit Area*

Test Pit Excavations – Twelve test pits were excavated within and around the perimeter of the CMP to characterize shallow fill materials and delineate the limits of the pit and/or fill material (Figure 5). The test pits excavated along the inferred perimeter of the CMP verified the CMP boundaries, showing clear indications of steepening bedrock slopes with the thickness of fill material increasing toward the central part of the pit. Subsequent soil borings drilled within the CMP confirmed these findings. Observations during text pit excavations included the following:

- Organic soils in the top 2 feet bgs.
- Debris from the surface to approximately 13 feet bgs (e.g., aluminum cans, glass, commercial paint, tires, scrap metal) mixed with coarse-grained soils and intermittent layers of soil fill and some mine tailings.
- An unidentified black, semi-solid, tar-like to grease-like substance mixed with soil in TP-01 and TP-02.
- Several intact drums and drum remnants observed in TP-01.

Detailed descriptions of these findings are provided in the CMP RIR (ARCADIS 2013b).

Boring Installations – Six borings were advanced within the limits of the CMP Area to characterize the deeper fill material used to backfill the pit (Figure 5). Conceptual cross sections are provided on Figures 3 and 4 in the CMP RIR.

The CMP consisted mainly of miscellaneous solid waste intermixed with fill cover soils, minor amounts of mine tailings, and mine waste rock overlying rock rubble. The solid waste and cover soils ranged in thickness from less than 1 foot at the edges of the pit to 47 feet in the central part of the pit (see the log for CMI-S4 in Appendix E of the CMP RIR [ARCADIS 2013b]). Soil features in the upper fill material were characteristic of periodic rain infiltration and poor drainage. Groundwater was encountered in the deeper soil borings at a depth of approximately 50 feet bgs, which is below the solid waste maximum thickness of 47 feet bgs; therefore, groundwater is not in direct contact with the solid waste in the pit.

Rock rubble formed the basal layer of pit fill material and was encountered from 10 to 53 feet bgs. Based on the boring logs, the rock rubble layer is estimated to fill more than 75 percent of the pit volume and originated from rock blasting to close the CMP pit, and other pits in the CMP Area, in 1965 (Pustay 1992).

A soil/solid waste sample was collected from each 10-foot core recovered during the advancement of the six borings conducted through the fill material in the CMP. Note that soil samples could not be collected from cores of rock rubble. The analytical results for soil samples collected as part of the CMP RIR (ARCADIS 2013b) were compared to the 2008 NJDEP Residential Direct Contact Soil Remediation Standards (RDCSRS) and IGWDSSL and are summarized in Section 5. The results were also included in their entirety in the CMP RIR (ARCADIS 2013b).

4.7.1.3 *O'Connor Disposal Area*

Fourteen test trenches and 10 test pits were initially completed during two field events (July/August 2006 and March 2007); these are shown on Figures 8A (includes summary logs) and 8B.

Test Trench Excavations – Test trenches were excavated along the perimeter of the OCDA to delineate the edge of fill and the edge of the former slime pond berm, and to characterize the nature and quality of fill and soil near the perimeter of the OCDA.

Test Pit Excavations – The test pits were excavated within the boundaries of the OCDA to assess the composition and vertical profile of the interior portion of the area. Five test pits were excavated in each of the two halves of the OCDA for a total of 10 test pits.

Observations during these excavations confirmed the previous understanding that the OCDA was used for the settling of slime tailings and disposal of mine tailings during historical mining activities and, later, for disposal of miscellaneous waste materials indicative of a landfill operation.

Results of the excavations showed that the uppermost landfill layer is extensive and matches up topographically with the former slime pond and other mine tailings disposal areas shown on old mine maps, which define most of the OCDA. Fill materials in many of the excavation areas included debris (including refuse and rubbish) intermixed with mine tailings and reworked soils. The fill was commonly observed along the length of the OCDA fronting Peters Mine Road; the fill material/debris was thicker in the central part of the OCDA and thinned toward Peters Mine Road, to the east toward Park Brook, and to the south where mine waste rock is prevalent in the subsurface.

The extent of former landfilling operations was clearly delineated at most locations. The results of these excavations indicated that landfilling operations did not extend entirely across the northeastern wetland area and did not extend up to the slime pond berm at all points.

Some paint waste chunks and fragments were observed in the OCDA in addition to paint waste identified at several surface locations. Paint waste flows were uncovered in the southern part of the OCDA, adjacent to Peters Mine Road, as well as at the northern edge of the OCDA. Paint waste, drums, and/or drum remnants were segregated and ultimately disposed offsite at approved facilities. The soil, fill, and debris material removed from the test pits and trenches during excavation, other than the paint waste, drums, and/or drum remnants, was returned to the excavation from which it was taken and the test pit areas were restored.

Supplemental Clearing and Test Trenching Activities – ARCADIS performed supplemental clearing and test trenching activities within the OCDA in 2010 to provide additional subsurface characterization. Ford completed 3,169 linear feet of trenching (eight test trenches) as part of the supplemental test trench investigation (Figure 8B). The analytical results are summarized in Section 5 and presented in their entirety in Table 7 of the OCDA RIR (ARCADIS 2013c).

4.7.2 Geophysical, Bedrock, Packer Testing, and Fracture Investigations

4.7.2.1 *Peters Mine Pit Area*

Bedrock investigations included drilling and logging boreholes in bedrock at well locations RW-5 through RW-7, RW-11, and RW-12; downhole geophysics; and packer testing to investigate water-bearing fractures identified by the downhole geophysical survey (Figure 6). The geophysical logs and the report prepared by Geophysical Applications, Inc. were included in Appendix F of the PMP RIR and are included as Appendix D. It should be noted that wells RW-5 through RW-7 were originally named wells MW-19BR through MW-21BR, respectively, and are labeled as such on the geophysical logs included in Appendix D.

Downhole geophysical televiewer data were used to plot rose diagrams to indicate the predominant down-dip azimuths of planar features observed in each well. The rose diagrams (Figure 9) depict the dip of the fracture orientations, which align with the flow pathway for groundwater. The majority of the fractures at the bedrock well RW-6 and RW-7 locations strike northeast-southwest, while open fractures strike eastnortheast-westsouthwest and closed fractures northwest-southeast at bedrock well location RW-5. Open and closed fracture strikes at RW-11 appear to be oriented northwest-southeast. The strike of bedrock fractures for wells RW-3/3D/3DD, RW-5/5A, and RW-11 are consistent with the overall groundwater flow direction within the bedrock aquifer, whereas wells RW-6/6A, RW-7, and RW-13 have primary fracture orientations almost perpendicular to the groundwater flow direction.

The geophysical borehole logs indicate that the bedrock is consistent with historical geological information and is mainly composed of foliated gneiss, which is crystalline, metamorphic rock. The borehole completion logs for bedrock well locations RW-3D and RW-11, including angled overburden monitoring well SC-01 located within the PMP Area, are provided in Appendix E of the PMP RIR (ARCADIS 2012c).

Potential packer testing intervals were identified using the geophysical data and were proposed to USEPA. After review and discussion, USEPA approved the packer testing intervals on April 27, 2006. The same packer intervals were monitored again during the September/October 2006 and April 2007 sampling events.

Bedrock monitoring wells RW-11 and RW-3 were sampled using inflatable packers to isolate specific intervals for groundwater sampling. Following agency approval of the packer intervals, the following packer testing intervals were sampled with RW-11 and RW-3D during the May/June 2010 and May 2011 monitoring event:

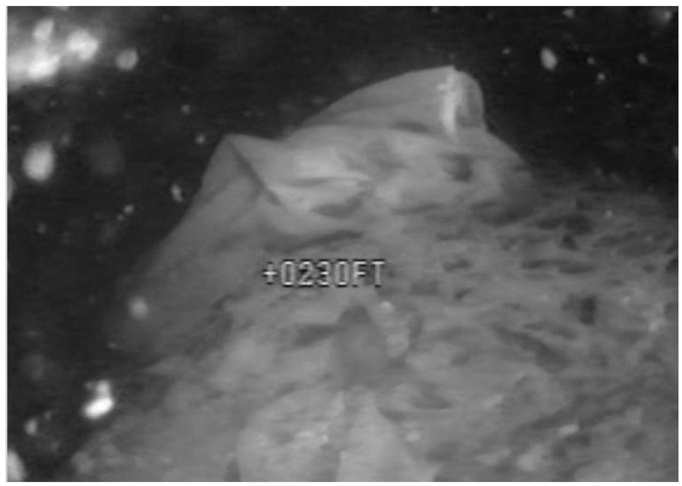
Well ID	Packer Intervals
RW-11	100 to 125 feet bgs 142 to 167 feet bgs 246 feet bgs (higher yield fracture) 252 to 272 feet bgs (below base of PM Air Shaft)
RW-3D	140 to 165 feet bgs 170 to 181 feet bgs

The packer interval of 221 to 246 feet bgs within bedrock well RW-11 was chosen due to an apparent higher flow rate (greater than 30 gpm) observed during well installation. This fracture was considered to be in possible hydraulic connection with groundwater within the PM inclined shaft because it is located at a depth similar to the base of the air shaft where the air shaft intersects the inclined shaft. This potential hydraulic connection with the shafts and the shallower underground mine workings would, therefore, present an effective means of verifying and monitoring groundwater quality within the portions of the mine that correspond to a depth of approximately 220 to 250 feet bgs.

The packer interval of 252 to 272 feet was chosen because it is deeper than the base of the PM Air Shaft, and would provide an indication of whether any constituents in groundwater within the air shaft, including residual benzene, are migrating at depth within the bedrock. The packer intervals within bedrock well RW-3D were chosen to correspond with the projected depth of the PM Air Shaft at that well location several hundred feet downgradient and to the southeast of the PMP.

An evaluation of bedrock fractures observed during geophysical logging indicates that for the five bedrock wells in the PMP Area (wells RW-3, RW-5, RW-6, RW-7, and RW-11) the number of open fractures decreases as a percentage between the upper and lower halves of the rock borehole (Table 8). The decreased range from a difference of 1% (four open fractures out of a total of 28 fractures in the upper 60 feet in RW-5 compared to five open fractures out of a total of 38 fractures in the lower 60 feet) to 22.5% (15 open fractures out of a total of 50 fractures in the upper 80 feet of RW-3D [30% open fractures] compared to seven open fractures out of a total of 93 fractures in the lower 80 feet [7.5% open fractures]).

At the bedrock well RW-11 location in the vicinity of the PM Air Shaft, the ratio of open/total fractures per 80-foot interval of rock borehole decreases downward so that the following is observed: 10/78, 12/92, 7/109. The low percentage of open fractures and the typical decrease in open fractures with depth is supported by the low yield of the monitoring wells, such that groundwater extraction rates to minimize drawdown during purging range from 3.5 milliliters/minute (mL/min) to 252 mL/min with an average sustainable rate of 93.6 mL/min (Table 8).



ARCADIS used a Geovision Model #GVJR H-D M2 camera to perform the downhole video work in the PM Air Shaft in April 2007 (ARCADIS 2007b); a video image is shown below. The Geovision camera was equipped with a high-resolution, low-light black and white lens, and fitted with auxiliary light-emitting diode (LED) lighting for use in an underwater environment. The camera was supported through the use of a “pipe string” constructed of ¾-inch chlorinated PVC piping for strength, and to allow rotation of the camera at various depths. Video was fed to a television equipped with an integrated videocassette recorder (VCR) to allow simultaneous viewing and recording of features within the air shaft. ARCADIS lowered the camera into the air shaft at a total of five locations, consisting of the shaft center and each of the four sidewalls. A 360-degree pan was performed at 10-foot intervals throughout the descent, where possible.

ARCADIS was able to reach the bottom of the air shaft on each of the five logging runs. Water within the air shaft was turbid to a depth of approximately 170 feet, but cleared markedly below this depth. Based on the video obtained, ARCADIS drew the following conclusions regarding the air shaft:

- The total estimated depth of the air shaft was 232 feet below the water surface, or approximately 234 feet below the top of the concrete collar around the air shaft.

- The concrete collar extends to a depth of approximately 20 feet bgs. Below the concrete collar, the sidewalls are exposed bedrock to the bottom of the air shaft.

- The air shaft was open but obstructed to some extent by large timbers or tree limbs encountered in the center of the shaft and along the west wall at a depth from approximately 120 to 169 feet below the surface of the water.

- What appear to be two remnant horizontal shafts intersect the air shaft. Both shafts were visible to the east and west; however, the shafts were seen most clearly along the west wall (facing the PMP) at a depth of approximately 180 feet and at a depth of approximately 200 to 232 feet. The lower shaft appears to be larger, corresponds to the depth that the inclined mine shaft is expected to be encountered, which slopes downward to the northeast.

- Silty sediment and leafy debris were observed at several depths along the wall of the air shaft, along the top of bedrock outcroppings, ledges, and the timber/tree limb obstructions. A pile of sediment and/or what appeared to be leafy debris was present at the base of the air shaft.

- No distinct crevasses or fractures were visible within the face of the bedrock on any of the four walls of the air shaft.

- Little or no water movement was observed within the air shaft, including at the base of the air shaft where it intersects the inclined mine shaft.

4.7.2.2 *Cannon Mine Pit Area*

A geophysical investigation was conducted by Vibra-Tech Engineers, Inc. in the vicinity of the CMP Area from July 26 through July 28, 2006 to identify potential subsurface voids in the vicinity of the CMP through the use of geophysical techniques. The geophysical investigation report is provided in Appendix G of the CMP RIR (ARCADIS 2013b) and is also provided in this RIR as Appendix D. The geophysical investigation consisted of an automated electrical resistivity sounding scan and a seismic refraction survey conducted along three investigation lines. These investigation lines were located along an intersecting network of dirt roadways/trails that traverse the location of the CMP and New London Pit Area. In general, the results of the geophysical investigation confirmed the locations of potential voids consistent with the review of aerial photographs and historical literature.

Downhole geophysical surveys were also performed on March 12 and 13, 2008 in each of the three bedrock boreholes at the well RW-8, RW-9, and RW-10 locations, which are shown on Figure 7. Geophysical logs were provided in Appendix H of the CMP RIR (ARCADIS 2013b) and are included as Appendix E. The purpose of the geophysical investigation was to identify potential groundwater transmissive fractures for groundwater level monitoring and sampling through packer testing. The geophysical methods utilized included a downhole acoustic televiewer, heat pulse flow meter, caliper, and monitoring of fluid resistivity, fluid temperature, and spontaneous potential. The geophysical results were used to identify the potential packer testing intervals. Although the caliper and acoustic televiewer logs suggested that a number of fractures may be present in the boreholes, the fluid resistivity and temperature logs and spontaneous potential readings indicated that the number of potentially transmissive fractures was small. Moreover, the heat pulse flow meter results indicated that groundwater yield in fractures was very limited.

Using the downhole geophysical data, a total of 12 packer testing intervals were selected, including three in borehole RW-8, four in borehole RW-9, and five in borehole RW-10. The 12 selected packer testing intervals were summarized in Table 7 of the CMP RIR (ARCADIS 2013b). The intervals were proposed to USEPA in a letter dated June 13, 2008 and approved by USEPA in an email on June 17, 2008. The packer testing was performed in July 2008 to test target potential water-bearing fractures within the boreholes for possible long-term monitoring.

The selected intervals were isolated using packers inflated with nitrogen with pressures up to 300 pounds per square inch. The vertical and horizontal hydraulic gradients were also interpreted within packer testing intervals by monitoring water levels with pressure transducers. Low-flow groundwater sampling of the packer intervals was conducted in July 2008 on 11 of the 12 proposed test intervals (the shallowest interval [22 to 42 feet] in borehole RW-10 did not yield sufficient water for sample collection).

Continued sampling of deeper bedrock wells in the CMP Area has shown that only 10 of 15 sampling intervals are capable of yielding enough groundwater within a single day to sufficiently and consistently fill the sample containers required to analyze for the full suite of parameters (Table 9). As indicated in Table 9, nested bedrock wells RW-8 and RW-9 rarely yield sufficient groundwater for sampling and collection of a complete set of samples for the full analytical suite. The sustainable groundwater extraction rates from bedrock wells within the CMP Area range from less than 1 mL/min to 150 mL/min with an average of 59 mL/min, which is extremely low and indicative of the low groundwater transmissivity of the crystalline bedrock at the Site.

The groundwater samples were collected from the bedrock wells and analyzed for TCL VOCs, SVOCs, PCBs, and TAL metals. The groundwater analytical results were compared to the NJDEP Groundwater Quality Standards (GWQS) and are further discussed in Section 5.

Similar to the PM Air Shaft, ARCADIS conducted a video log of the CM Shaft on March 16, 2010 (ARCADIS 2010c). A 6-inch-diameter steel riser pipe, visible at the ground surface, penetrated the concrete cover and continued into the water beneath the cover. The pipe appeared to be supported on two sides by angled iron laid on top of the rails. The pipe could be moved and swung freely in the water below, indicating it was not secured at depth.

ARCADIS used a Geovision Model #GVJR H-D M2 camera to perform the downhole video work in the air shaft. The Geovision camera was equipped with a high-resolution, low-light black and white lens, and fitted with auxiliary LED lighting for use in an underwater environment. The camera was supported on a “pipe string” constructed of 1-inch steel rods to allow rotation of the camera at various depths. Due to the weight of the rods, ARCADIS subcontracted with Summit Drilling to provide labor and equipment to attach the rods in 20-foot lengths and lower the pipe string into the shaft. Video was fed to a television equipped with an integrated VCR to allow simultaneous viewing and recording of features within the air shaft.

ARCADIS then lowered the camera into the air shaft through the hole in the cover located at the former riser pipe. This hole was near the center of the shaft, but biased slightly toward the shaft wall facing the CMP. It was not possible to lower the camera through the cap at any other location. A 360-degree pan was performed at approximately 50-foot intervals throughout the descent, where possible. Note that the video equipment was able to reach a maximum depth of 379 feet within the shaft before refusal was reached due to remnant mining operation debris within the shaft.

Water within the shaft appeared clear throughout; however, cables and other debris within the shaft were coated with grease that smeared onto the camera and cable on removal. Based on the lack of movement of suspended particles within the water column, little or no water movement was detected throughout the decent to the base of the shaft. Note that the groundwater within the CM Shaft was sampled as part of the 2012 Site-related groundwater annual sampling event, and there were no constituents reported other than metals native to the bedrock and reflective of historical mining operations as discussed in detail in Section 5.

5. Remedial Investigation and Monitoring Results

This section presents the groundwater and surface water analytical results for the Site as well as key historical results and other data and analyses collected to support remedial decision-making at the Site. This section includes the following information:

- Sources and distribution of constituents - Multiple investigations have been completed to understand the nature and extent of potential source areas within the three ACs at the Site. These data are presented below to facilitate understanding of the CSM for each AC and the overall Site. These data are presented in more detail in RI Reports for each AC (ARCADIS 20123b, 2012b, 2012c).

- Groundwater results – data from 2005 through 2014 are evaluated to define the nature and extent of constituents, specifically, the primary COCs—benzene, lead, and arsenic—in groundwater. Data tables and figures are referenced to supplement the discussion.

- Surface water results – data from 2004 through 2012 are evaluated to define the nature and extent of constituents, specifically benzene, lead and arsenic, in surface water. Data tables and figures are referenced to supplement the discussion.

- Vapor intrusion evaluation – the results of the 2012 vapor intrusion evaluation are presented.

Groundwater elevation data were also collected during groundwater investigation activities. Groundwater contour maps were created for the three ACs based on data collected in 2012, 2013, and 2014 (Tables 10, 11, and 12) for both shallow and deep bedrock as shown in Figures 10 through 15.

5.1 O'Connor Disposal Area Results

5.1.1 OCDA Sources and Distribution of Constituents

Lead and arsenic have been detected in soil above their relevant screening levels within the OCDA. Soil samples collected from OCDA test pits had detected concentrations of lead with a maximum of 470 milligrams per kilogram (mg/kg) which is above the NJDEP 2008 IGWDSSL of 59 mg/kg and the Residential Direct Contact Soil Screening Level (RDCSSL) of 400 mg/kg, and arsenic with a maximum of 126 mg/kg which is above the NJDEP 2008 IGWDSSL and RDCSSL of 19 mg/kg.

Surface soil samples collected in the OCDA had detected concentrations of lead with a maximum of 155 mg/kg, which is above the NJDEP 2008 IGWDSSL of 59 mg/kg but below the RDCSSL of 400 mg/kg, and concentrations of arsenic with a maximum of 51 mg/kg which is above the NJDEP 2008 IGWDSSL and RDCSSL of 19 mg/kg.

Complete analytical results for surface soil samples are summarized in Table 4 of the OCDA RIR (ARCADIS 2013c). Analytical results for soil samples collected from the initial test pits and trenches are summarized in Table 6 of the OCDA RIR, and analytical results for soil samples collected from supplemental test pits and trenches are summarized in Table 7 of the OCDA RIR (ARCADIS 2013c). Results for other constituents analyzed for soil samples collected from the OCDA indicate the following:

- No VOCs have been detected in any OCDA surface soil samples at concentrations above the NJDEP IGWDSSL or RDCSSL and only two samples from test pit/trenches had detected VOC concentrations above their respective IGWDSSL for ethylbenzene, toluene, total xylenes, and trichloroethene (TCE).

- No SVOCs have been detected above the IGWDSSL in any of the surface soil samples collected from the OCDA. SVOC analytical results indicate that three polycyclic aromatic hydrocarbons (PAHs) [benzo(a)anthracene, benzo(a)pyrene and benzo(b)fluoranthene] were detected at concentrations above their respective IGWDSSL in five test pit/trench samples collected at the OCDA.

- Total PCBs were detected at concentrations above the IGWDSSL of 0.2 mg/kg in one surface soil sample and in 11 test pit/trench samples with a total PCBs maximum concentration of 1.13 mg/kg.

- Of the 23 TAL metals, one or more were detected at concentrations above their respective IGWDSSL in soil and test pit/trench samples collected in the OCDA.

5.1.2 Groundwater Results

Groundwater results from 2004 through 2014 are presented in Table 13 and are summarized in Figures 16 through 18 noting where concentrations of the primary COCs exceed the relevant criteria. The enclosed Table 13 summarizes the groundwater analytical results for benzene, lead, and arsenic only for all wells at the Site for the entire period of monitoring to make it easier to evaluate the concentration trends over time. The table that summarized analytical results for all constituents are presented in Appendix F and laboratory analytical reports are presented in Appendix G. Analytical results generated from the RI groundwater monitoring program for overburden wells installed within the OCDA indicate the following:

- No VOCs have been detected in groundwater samples at concentrations above GWQS with the single exception of methyl tertiary-butyl ether (MTBE) at monitoring well OB-25 which is located upgradient of the OCDA and across Sheehan Drive from a former automobile junkyard. MTBE was detected above the GWQS of 70 µg/L with a concentration of 171 µg/L during the July 2009 sampling event. However, MTBE was not detected above GWQS at any other well location in 2009 nor has it been detected above GWQS in any other groundwater sample collected as part of the OCDA RI, including the most recent 2014 event.

- Given that MTBE was not in wide use in the United States prior to the mid-1980s, the data indicate that the single MTBE detection in groundwater at upgradient well OB-25 is not associated with fill materials within the OCDA.

- No SVOCs have been detected in groundwater in the OCDA at concentrations above their respective GWQS during any of the RI sampling events, including the most recent 2014 event, with the exception of two single detections of bis(2-ethylhexyl)phthalate at OB-23 (6.6 µg/L) and OB-25 (3.7 µg/L) during the April 2007 groundwater monitoring event.

- No pesticides or PCBs have been detected in groundwater samples in concentrations above the GWQS in any of the groundwater samples collected from the OCDA during the RI.

- Certain TAL metals have been detected in groundwater samples at concentrations above their respective GWQS as summarized below and in Table 13:

  - Total aluminum has historically been sporadically detected at concentrations above the GWQS of 200 µg/L at wells OB-14B, OB-17 (only once since 2004), OB-18, OB-21, OB-22, OB-24, OB-25, and OB-28.

  - Total and dissolved iron has historically been detected at a concentration above the GWQS of 300 µg/L at all of the OCDA monitoring wells. These results may be reflective of native soil and bedrock, historical mining, and isolated groundwater geochemical conditions in certain portions of the OCDA that would enhance iron solubility in groundwater.

  - Total manganese has historically been detected at concentrations above the GWQS of 50 µg/L at wells OB-14A, OB-14B, OB-16, OB-17, OB-22 and OB-23, OB-24, OB-25, and OB-28. These results may be reflective of native soil and bedrock, historical mining, and local groundwater geochemical conditions.

  - Total arsenic has historically been sporadically detected at concentration above the GWQS of 3 µg/L at wells OB-14A, OB-16, OB-17 (only once in 2014), OB-22, OB-25, and OB-28 (only once in 2011).

- Total lead has historically been sporadically detected at concentration above the GWQS of 5 µg/L at wells OB-22, OB-23, OB-25, and OB-28(only once in 2011).

Lead has been detected sporadically as total lead in OCDA groundwater samples at concentrations above the 5 µg/L GWQS; however, since 2011, lead has only been detected in groundwater as total lead at concentrations above the GWQS in samples collected at well OB-25 with a concentration of 40.3 µg/L reported in 2013. This well is located upgradient of the OCDA and adjacent to a former automobile junkyard that is known to have been present on the northwestern corner of Peters Mine Road and Sheehan Drive. These data indicate that lead detected in groundwater at this location is more likely associated with the former automobile junkyard and is not reflective of fill materials placed within the OCDA. Well OB-25 is also located downgradient from a residential property where automotive repair and storage activities are frequently observed.

Total arsenic has been detected at levels exceeding the GWQS of 3 µg/L in five OCDA overburden monitoring wells, including OB-14A, OB-16, OB-17, OB-22, and OB-25. At the upgradient well OB-25 location, total arsenic has been detected at concentrations above the GWQS since 2004, with a maximum concentration of 19.8 µg/L in 2008. However, dissolved arsenic has not been detected in filtered samples at concentrations above the GWQS.

As summarized in Table 13, there have been no exceedances of total or dissolved arsenic or lead in groundwater samples collected from monitoring well OB-18 located downgradient of the OCDA.

Iron and manganese in the dissolved form have been detected at concentrations above their respective GWQS and are associated with moderately to strongly reducing conditions demonstrated by low dissolved oxygen (DO) concentrations and low (e.g., negative) oxidation-reduction potential (ORP) values which causes these metals to occur in a more soluble form. The moderately to strongly reducing groundwater conditions in the OCDA overburden groundwater are likely reflective of oxidation and/or microbial degradation of organic carbon-containing materials within the OCDA fill (e.g., wood, leaves, paper).

Arsenic and, to a lesser extent aluminum, are also reactive to changes in redox conditions in the groundwater; however, neither metal is prevalent in the dissolved form in groundwater within the OCDA, or elsewhere at the Site. The extensive groundwater analytical data base and geochemical data generated during the RI indicate that, although these metals are present in the soil/groundwater system, filtered groundwater sample data indicate they are not in a form that is readily available for dissolution into groundwater. Therefore, detected concentrations of total aluminum and total arsenic in groundwater largely represent particulates in the groundwater as opposed to fully dissolved into solution.

This interpretation of groundwater metals data is reinforced by the influence of groundwater turbidity due to suspended particulates on the detected concentration of various metals. For example, with respect to lead, a total lead concentration of 53.6 µg/L was detected in the sample collected from well OB-25 during the June 2010 sampling event and the unfiltered turbidity for this sample was 797 nephelometric turbidity unit (NTUs), well above the target NTU level of 5, whereas lead was not detected in the filtered sample. The sample collected from well OB-25 during the April/May 2012 sampling event had a total lead concentration of 17.2 µg/L and turbidity measured at 24.1 NTUs whereas lead was, once again, not detected in the filtered sample. The NJDEP guidance for low-flow groundwater purge and sampling sets a goal of 5 NTUs for sample turbidity based on recognition that elevated turbidity can result in metals concentrations that are biased higher than they actually are in the groundwater, as the data indicates is the case at the aforementioned locations.

Moreover, with respect to arsenic, a total arsenic concentration of 9.1 µg/L was reported in the May 2011 sample collected from well OB-16 with a sample turbidity of 15.9 NTUs but the filtered sample reported arsenic at a concentration of 6 µg/L. During the April/May 2012 sampling event, total arsenic was reported at a concentration of 6.9 µg/L in a groundwater sample collected at well OB-16, with a turbidity of 25.7 NTUs. However, the filtered sample arsenic result was below GWQS with a reported concentration of 1.5B µg/L (and arsenic was also detected in the blank). In November 2013, arsenic was reported above its 3 µg/L GWQS in both the total and filtered samples, but the ORP value was -64 millivolts, which indicates that the arsenic was in dissolved form due to reducing conditions. In September 2014, total arsenic was reported above its 3 µg/L GWQS, however, the concentration of dissolved arsenic reported in the filtered sample was less than the GWQS and the detection limit of 2.6 µg/L. Note that the groundwater ORP at this well is -87 millivolts and the turbidity was zero NTUs. As previously discussed in Section 4.6.6, the results of a supplemental arsenic evaluation conducted as part of the RI at select well locations using both USEPA Methods 6010C and 7062 indicates that historical arsenic concentrations which were reported using Method 6010C were likely biased high due in part to interference from REEs in addition to elevated sample turbidity and reducing groundwater conditions, depending upon the well location.

Finally, as previously stated, the constituents reported in groundwater samples collected at upgradient groundwater monitoring well OB-25 are not consistent with constituents detected in groundwater samples collected at the other OCDA well locations. Historically, groundwater samples collected at well OB-25 had concentrations of lead and bis(2-ethylhexyl)phthalate (once in April 2007 at 3.7 µg/L) above GWQS in addition to beryllium, cadmium, mercury, and arsenic and detected concentrations of copper, zinc, cobalt, and nickel. Since well OB-25 is located in native soil upgradient of the OCDA, the data indicate that the constituents detected in groundwater at this location are likely not associated with fill materials historically deposited within the OCDA.

5.1.3 OCDA Surface Water Results

Surface water results from 2004 through 2012 are presented in Table 14 and are summarized in Figures 16A, 17A, and 18A noting where concentrations of the primary COCs exceed the relevant criteria. Surface water analytical results for samples collected in Park Brook located adjacent to and downgradient of the OCDA indicate the following:

- No TCL VOCs, SVOCs, PCBs, pesticides, or TAL metals were detected above their respective Surface Water Quality Standards (SWQS), with the exception of arsenic, which was detected above its SWQS in surface water sample locations SW- PAB-01A (0.72 µg/L) and SW-PMB-01 (2 µg/L) in 2012 and antimony, which was detected once during the November 2005 sampling event at sample location SW-PAB-03 (6.4 µg/L) but was not detected above the SWQS since that time.

With respect to the Peters Mine Brook sample location SW-PMB-01, located downstream of the Borough of Ringwood Recycling Center:

- Total lead and arsenic have been detected at concentrations above their respective SWQS with detected concentrations of 5.2 µg/L and 2 µg/L, respectively.

5.2 Cannon Mine Pit Area Results

5.2.1 Sources and Distribution of Constituents

As summarized in Table 1 of the CMP RIR (ARCADIS 2013b), the CMP Area surface soil analytical results indicate no TCL VOCs, SVOCs, or PCBs, or TAL metals at concentrations above their respective RDCSRS. In addition, the analytical results for soil samples collected from borings completed within the CMP indicate no VOCs above their respective RDCSRS. Several SVOCs were detected at concentrations above their respective RDCSRS, including several PAHs, bis(2-ethylhexyl)phthalate, and PCBs.

Of the TAL metals, antimony, arsenic, lead, and vanadium were detected sporadically in CMP soil samples at concentrations above RDCSRS. However, each of these constituents was sporadically detected in soil samples with no consistent spatial pattern and at concentrations only moderately above NJDEP RDCSRS. These results reflect isolated, low-level constituent concentrations associated with heterogeneous fill material of the type placed within the CMP.

Blast rock samples consisting of fine sand to pebble-sized particles were collected from soil borings completed within the CMP. B last rock sample analytical results indicate that no TCL VOCs, SVOCs, or PCBs and no TAL metals were detected at concentrations above their respective NJDEP RDCSRS.

Several drums removed from the CMP Area during the excavation of test pits contained PCB Aroclors 1242 and 1260 at concentrations above the Total PCB RDCSRS of 0.2 mg/kg; however, these same Aroclors were not detected in samples collected from fill material in soil borings completed within the pit. Three of the drums removed from the pit also contained barium or lead at concentrations that exceeded the criteria for characterization as a hazardous waste when analyzed using the Toxicity Characteristic Leachate procedure.

Comparisons of 31 soil samples collected during the CMP RI to the NJDEP RDCSCC/RDCSRS and the IGWSCC/IGWDSSL are summarized in Tables 3 and 4 of the CMP RIR (ARCADIS 2013b), respectively. Results are summarized here in comparison to the IGWDSSL:

- VOCs – Three of the 31 soil samples had detected VOC concentrations above their respective IGWDSSL. These include benzene, chlorobenzene, ethylbenzene, toluene, and total xylenes.

- SVOCs – One of the 31 soil samples had detected SVOC concentrations above the IGWDSSL, including two PAHs, benzo(a)anthracene, and benzo(a)pyrene.

- PCBs – Two of the 31 soil samples had total PCB concentrations above the IGWDSSL of 0.2 mg/kg.

- Metals – In each of the 31 soil samples, various metals were detected at concentrations above their respective IGWDSSL. These include two of the key constituents: lead (15 samples) and arsenic (three samples). Other metals include: aluminum (29 samples), antimony (11 samples), barium (one sample), beryllium (nine samples), cadmium (19 samples), manganese (31 samples), mercury (five samples), nickel (13 samples), silver (three samples), thallium (one sample), and zinc (13 samples).

5.2.2 CMP Area Groundwater Results

Groundwater results from 2004 through 2014 are presented in Table 13 and are summarized in Figures 16 through 18 noting where concentrations of the primary COCs (benzene, lead and arsenic) exceed the GWQS. Overall, groundwater analytical results generated during the RI for the CMP Area demonstrate that detection of constituents in groundwater above their respective GWQS are sporadic in frequency and are limited in extent to the immediate CMP Area. Specifically, the results indicate the following:

- TCL VOCs

  - Benzene was detected in groundwater samples collected from several packer test intervals within well RW-9 during sampling conducted in July 2008. Further assessment of the July 2008 results indicate that benzene was present in RW-9 groundwater as a result of improper sampling techniques. This was confirmed by subsequent sampling events conducted from 2009 through 2014, after completion of the open RW-9 borehole as a screened well. Groundwater data from all subsequent sampling events have demonstrated that benzene is not detected in groundwater at well RW-9.

- Benzene was detected in RW-8(204-214) at a concentration of 2.2 µg/L in 2013, and 0.5 µg/L in September 2014 after having been historically not detected.

- In September 2008 and October 2009, TCE was detected at a concentration above the GWQS of 1 µg/L in groundwater samples collected at monitoring well OB-3. However, TCE has not been detected in groundwater at this location, or at any of the other groundwater monitoring locations in the CMP Area, in subsequent rounds of sampling conducted in 2010, 2011, 2012, 2013, and 2014. These results confirm that the detection of TCE in groundwater was localized to OB-3 and was isolated in occurrence.

- TCL SVOCs

  - Bis(2-ethylhexyl)phthalate has sporadically been detected at concentrations above the GWQS (3 µg/L) in groundwater samples collected in the CMP Area but not during the 2013 or 2014 sampling events.

- Pesticides/PCBS

  - No pesticides or PCBs have been detected in groundwater samples collected within the CMP Area from the beginning of the RI through to the most recent sampling event in 2014..

- TAL Metals

  - Total arsenic and lead have been detected sporadically in groundwater samples collected in the CMP Area with no consistent spatial pattern. During the November 2013 sampling event, exceedances of the arsenic GWQS (3 µg/L) were reported at bedrock wells RW-2 (3.8 µg/L) at a depth of 462 feet, RW-9A (3.4 µg/L) at a depth of 95 feet, and RW-10 (9.5 µg/L) at a depth below grade of 195 feet. During the September 2014 sampling event, exceedances of the arsenic GWQS of 3 µg/L were reported at bedrock wells RW-2 (5.2 µg/L) at a depth of 289 feet, RW-2 (8.3 µg/L) at a depth of 462 feet, RW-9A (5.3 µg/L) at a depth of 95 feet, RW-9 (7.3 µg/L) at a depth of 216 feet, RW-10 (8.2 µg/L) at a depth of 130 feet, and RW-10 (7.9 µg/L) at a depth below grade of 195 feet; however, the data indicate that the reported concentrations may be biased high due to REE interference in addition to elevated turbidity and/or reducing groundwater conditions (See Section 4.6.6. for further details).

- Aluminum, iron, and manganese have been sporadically detected at concentrations above their respective GWQS in groundwater samples collected in the CMP Area, but generally at levels consistent with upgradient, background groundwater quality.

- With the exceptions of groundwater samples collected from packer testing activities in 2006, 2007, and 2009 at monitoring wells RW-1 (background location) and RW-2, zinc has not been detected at concentrations above the GWQS in groundwater samples collected from the CMP Area, including the most recent 2014 event.

5.2.3 CMP Area Surface Water Results

Surface water results from 2004 through 2012 are presented in Table 14 and are summarized in Figures 16A, 17A, and 18A noting where concentrations of the primary COCs exceed the relevant criteria. Surface water analytical results from samples collected within Mine Brook located adjacent to and downgradient of the CMP indicate the following:

- TCL VOCs

  - No TCL VOCs have been detected in surface water samples collected in the CMP Area.

- TCL SVOCs

  - As summarized on Table 14, the only SVOC detected above SWQS was bis(2-ethylhexyl)phthalate at upgradient sampling location SW-MRB-00 in 2012 at a concentration of 5 µg/L and at location SW-MRB-02 at a concentration of 3.5 µg/L. Bis(2-ethylhexyl)phthalate, was not detected at surface water monitoring locations SW-MRB-03 or SW-3 located further downstream.

- Pesticides/PCBS

  - No pesticides or PCBs have been detected in surface water samples collected in the CMP Area.

- TAL Metals

  - Total lead was detected above the SWQS of 5.0 µg/L at a concentration of 5.6 µg/L in April/May 2012 at sample location SW-MRB-01. Lead has not historically been detected at this or any other surface water sample location adjacent to or downgradient from the CMP Area.

- Total arsenic has been detected at concentrations above the SWQS of 0.017 µg/L in most surface water samples collected from locations adjacent to or downgradient from the CMP at concentrations ranging from 0.32 to 1.2 µg/L.

- Concentrations of thallium have historically been detected above the SWQS of 0.24 µg/L in surface water samples collected at locations SW-MRB-02 (0.27 µg/L) and SW-MRB-03 (0.77 µg/L) but thallium has not been detected above SWQS in recent rounds of sampling.

5.3 Peters Mine Pit Area Results

5.3.1 PMP Area Sources and Distribution of Constituents

Results from multiple investigations of fill materials and long-term monitoring of groundwater indicate that benzene occurs at low concentrations in fill material and at concentrations of 15 µg/L or less in groundwater within and downgradient of the PMP and at an average concentration of approximately 31 µg/L at the base of the PM Air Shaft based on sampling from 2006 through 2014. Note that the PMP Air Shaft was not sampled in 2013.

Soil samples collected from the three angled borings completed within the PMP indicated concentrations of lead (maximum of 8,300 mg/kg) above the NJDEP 2008 IGWDSSL (59 mg/kg) in 18 of the 38 soil samples and above the 2008 RDCSSL (400 mg/kg) in 7 of the 38 soil samples. In addition, soil samples collected from the three angled borings within the PMP had detected concentrations of arsenic (maximum of 82.9 mg/kg) above its NJDEP 2008 IGWDSSL and RDCSCL of 19 mg/kg in 20 of the 38 soil samples.

Other constituents have been sporadically detected in the PMP fill material, including total xylenes, several SVOCs, some PCB Aroclors, and TAL metals, including lead, arsenic, iron, manganese, aluminum, and vanadium. Detected concentrations of xylenes, SVOCs, and PCB Aroclors were sporadic and the majority of samples had constituent concentrations less than the NJDEP RDCSSL or IGWDSSL. A comparison of the 38 PMP Area soil sample analytical results to their respective IGGSCC and 2008 IGWDSSL was provided in Table 5 of the PMP RIR. The results are summarized below in comparison to the IGWDSSL:

- TCL VOCs – Eight of 38 soil samples had detected VOC concentrations above their respective IGWDSSL. These VOCs includes benzene (one of the three key constituents in the PMP Area), ethylbenzene, methylene, toluene, trichloroethene, and total xylenes.

- TCL SVOCs – Fifteen of 38 soil samples had detected SVOC concentrations above the IGWDSSL. SVOCs detected above the IGWDSSL included several PAHs, including: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Naphthalene, 2-methylnaphthalene, N-nitrosodiphenylamine, and pentachlorophenol were also detected at concentrations above their respective IGWDSSL.

- PCBs – Fifteen of 38 soil samples had detected PCB concentrations above the Total PCB IGWDSSL of 0.2 mg/kg.

- Pesticides – Five of 38 soil samples had detected concentrations of the pesticide dieldrin at concentrations above the IGWDSSL of 0.003 mg/kg.

- TAL Metals – Various metals were detected at concentrations above their respective IGWDSSL in the 38 soil samples, including two of the key PMP Area constituents: lead (18 samples) and arsenic (19 samples). Other metals include: aluminum (33 samples), antimony (nine samples), barium (two samples), beryllium (six samples), cadmium (11 samples), manganese (37 samples), mercury (21 samples), nickel (three samples), and zinc (nine samples).

5.3.2 PMP Pond Sediment Sampling Results

The analytical results generated by the sampling of the PMP Pond indicate that the majority of COPECs were not detected in the sediment samples. Of those detected, PCB Aroclor 1260 and bis(2-ethylhexyl)phthalate were the only organic compounds exceeding an LEL screening value. Several metals exceeded their respective LELs in one or more samples, including antimony, arsenic, cadmium, copper, lead, nickel, and zinc. Arsenic exceeded the LEL and SEL screening levels in five out of six sediment samples and is the only COPEC that exceeded an SEL value.

The analytical results generated by PM Air Shaft sediment sampling indicate that the majority of COPECs were not detected in sediment samples collected from the PM Air Shaft. The analytical results are provided in Appendix H. Of the COPECs detected, the only organic compounds that exceeded an LEL screening level are total xylenes, 2-methylnaphthalene, bis(2-ethylhexyl)phthalate, acenaphthene, and naphthalene. In addition, bis(2-ethylhexyl)phthalate is the only COPEC to exceed an SEL value. Note that benzene was detected at a concentration of 0.0463 mg/kg, which is below the LEL of 0.34 mg/kg. Several metals exceeded their respective LELs, including arsenic, copper, lead, nickel, potassium, and zinc.

5.3.3 Peters Mine Air Shaft Sediment Results

One sediment sample was collected from the PM Air Shaft on October 20, 2011 in accordance with the USEPA-approved PM Air Shaft Sediment Sampling (ARCADIS 2011b). The analytical results generated by PM Air Shaft sediment sampling indicate that the only organic compounds exceeding an LEL screening value were xylenes, 2-methylnaphthalene, bis(2-ethylhexyl)phthalate, acenaphthene, and naphthalene. Bis(2-ethylhexyl)phthalate was also the only COPEC to exceed a

SEL value. Benzene was detected at a concentration of 0.0463 mg/kg which is below the LEL of 0.34 mg/kg.

Sediment–water partitioning calculations were conducted to evaluate potential concentrations of benzene and bis(2-ethylhexyl)phthalate in water in equilibrium with PM Air Shaft sediment. Equilibrium partitioning is based on the amount of material that will sorb to a solid versus how much will remain in solution. General assumptions used in the sediment-water partitioning calculations included:

- Equilibrium partitioning from sediment to groundwater;
- Sufficient mass of constituents detected in sediment to account for the mass of constituents detected in groundwater;
- Default, literature-based partition coefficients are representative of partition coefficients of PM Air Shaft sediment; and
- Limited migration of groundwater from the shaft to bedrock or other portions of the underground workings.

The sediment-water partitioning calculation was performed using the following equations (USEPA 1996):

$$\mathbf{C_{water}\ (\mu g/L) = C_{sediment}\ (\mu g/kg) \ /\ K_d\ (L/kg)}$$

$$\mathbf{K_d = K_{oc} \times f_{oc}}$$

Where:

K_d is the sediment–water partition coefficient for the constituent;

$C_{sediment}$ is the concentration of the constituent in sediment;

C_{water} is the resulting concentration of the constituent in water in equilibrium with sediment;

K_{oc} is the organic carbon–water partition coefficient for the constituent; and

F_{oc} is the fraction of organic carbon in sediment.

Default values for K_{oc} used in the calculation include 66 L/kg for benzene and 114,337 L/kg for bis(2-ethylhexyl)phthalate) and an f_{oc} of 0.006 (USEPA 1996), resulting in K_d values of 0.396 L/kg for benzene and 686 L/kg for bis(2-ehtylhexyl)phthalate.

As summarized in the table below, based on these K_d values, and using measured concentrations of benzene and bis(2-ethylhexyl)phthalate in the PM Air Shaft sediment (0.0463 and 1.21 mg/kg, respectively) the sediment-water partitioning calculation results in concentrations of 117 µg/L of benzene and 1.8 µg/L of bis(2-ethylhexyl)phthalate in water in equilibrium with the sediment at the base of the PM Air Shaft. These values are consistent with the maximum detected concentrations of benzene and bis(2-ethylhexyl)phthalate (33.2 µg/L and 3.5 µg/L, respectively) in the PM Air Shaft groundwater samples collected at the base of the air shaft where the sediment sample was collected.

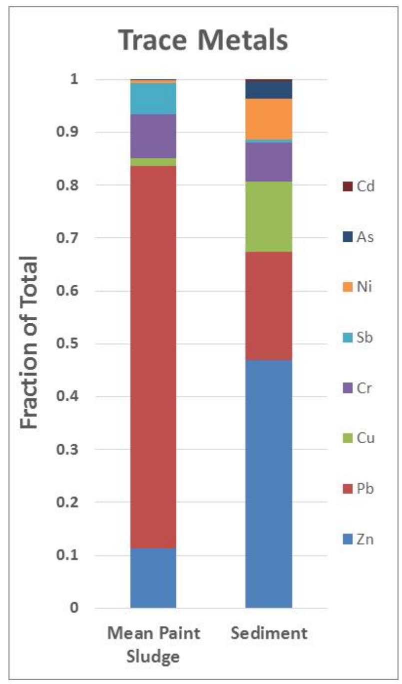
Constituent	K_{oc} (L/kg)	f_{oc}	K_d (L/kg)	$C_{sediment}$ (mg/kg)	C_{water} (µg/L)	PM Air Shaft Groundwater (µg/L)
Benzene	66	0.006	0.396	0.0463	117	33.2
Bis(2-ethylhexyl)phthalate)	114,337	0.006	686	1.21	1.8	3.5

The data suggest that benzene and bis(2-ethylhexyl)phthalate in the PM Air Shaft sediment could be a source of these constituents in the groundwater at the base of the PM Air Shaft. Since the above calculation is based on the primary assumption of equilibrium partitioning between the sediment and water in the air shaft and because there is a large volume of water in the shaft and only one sediment sample that was able to be collected at the base of the shaft, these results are considered qualitative. The calculation suggests that the sediments could be a source of constituents at the base of the PM Air Shaft because the differences between the measured concentration of constituents in air shaft groundwater and the estimated concentration based on equilibrium partitioning are small. In order to further assess whether the sediments at the base of the PMP Air Shaft could be contributing to constituents detected in the groundwater within the Air Shaft, a forensic evaluation was conducted.

5.3.4 Peters Mine Air Shaft Sediment Forensic Evaluation

A commonly used approach in forensic analyses is to first focus on data that are unaffected or least affected by degradation processes. The basic premise is that the “signature” of COCs in the impacted material must match that of the source material. By first focusing on non-degradable elements (i.e., metals) or compounds that are resistant to degradation (e.g., PAHs), similarities in impacted versus source material signatures (or lack thereof) can be resolved with little to no potential for error introduced by variable degradation processes.

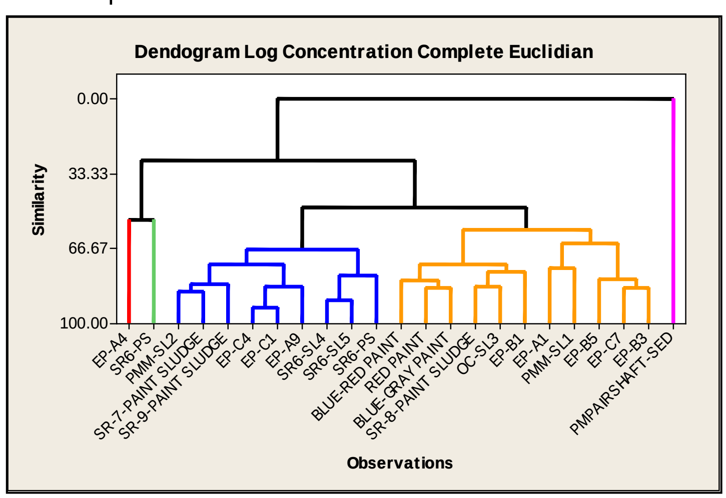
Therefore, the first step in the forensics analysis included a comparative analysis using 1) metals, given that they are elements that do not degrade *per se*, and 2) PAH compounds, given that many of these (including the 5 and 6 ring PAHS) are relatively resistant to degradation. After comparing the suites and relative concentrations of metals and PAH compounds found in the PM Air Shaft sediment sample to that of paint waste samples collected from the Site, the study then considers statistical comparisons and mixing models to further evaluate possible sources of the COCs and provide lines of evidence that consider the "signature" of the metals and PAHs in the sediment.



In addition to considering metals and PAHs, VOCs were included in the forensic analysis. Degradation of VOCs can represent some challenges when conducting a forensics analysis, but a baseline comparison of the types of VOCs detected and the relative degradation rates can provide insight on the likelihood of whether impacts are related to certain sources materials, or not.

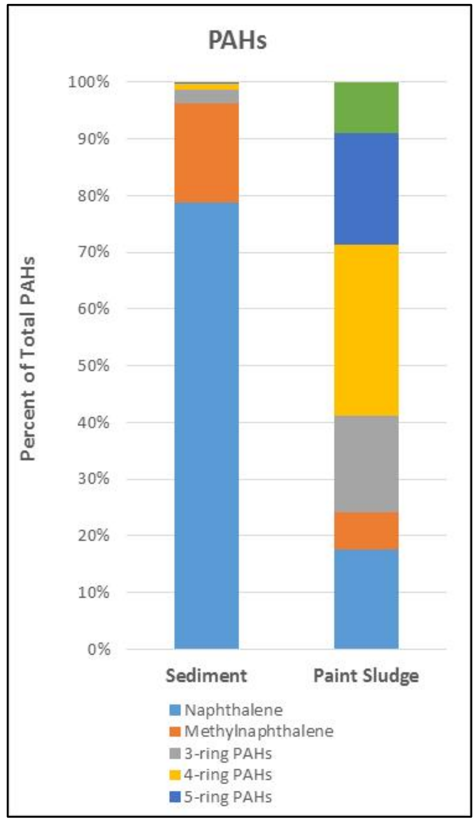
Trace Metals

The forensics analysis for metals shows that lead is the dominant metal in paint waste, with relatively higher proportions of antimony and chromium. In contrast, zinc is the dominant metal in sediment with higher proportions of copper, nickel, and arsenic, and lower relative concentration of lead and chromium. Moreover, as shown in the figure to the right, the relative proportions of the metals found in sediment do not match the relative proportions of the metals found in the paint waste samples.



In addition to the analysis provided above, a Multivariate Cluster Analysis (MCA) was conducted. A MCA statistically groups samples based on the overall similarity in composition given the relationships between target metals within the samples. The findings of the MCA indicate that the PM Air Shaft sample (shown in pink) is clearly separate and unrelated to paint waste samples. Given that degradation processes do not affect concentrations or distributions of metals, this comparative analysis provides a primary line of evidence that metals in the sediment sample are not related to paint waste.

PAHs



Per the information presented in this document, the PAHs comparisons revealed remarkably different PAH profiles for the sediment and paint waste. Paint waste is dominated by naphthalene and 2-methylnapthalene (2-ring PAHs) with traces or non-detect concentrations of other PAHs. In contrast, the PM Air Shaft sediment contains a full spectrum of PAH compounds, including 5 and 6 ring PAHs that are more resistant to degradation and are not detected in paint waste samples. Moreover, as shown in the figure to the right, the relative proportions of PAHs in sediment do not match the relative proportions of PAHs in the paint waste samples.

For PAHs, degradation can cause some shift in PAH concentrations in the more degradable compounds, like naphthalene and 2-methyl naphthalene. However, as shown on Figure I-1 (Appendix I), the similarity in magnitudes of PAH compounds detected in the 1987 paint waste samples compared with the 2006 and 2007 paint waste samples, especially with respect to the content of the most degradable PAHs, naphthalene and 2-methyl naphthalene, indicates limited degradation of PAHs has occurred in paint waste samples over the approximately 20 year time span between sample collection and analysis events. It should be noted that samples analyzed in 2006 and 2007 had substantially lower laboratory detection limits than in 1987; therefore more PAHs were detected (at low concentrations) as compared with 1987 samples. However, the general distributions for both time periods demonstrate dominance by naphthalene and 2-methyl naphthalene for all paint waste samples.

Degradation cannot account for the differences in the presence or absence of individual PAH compounds in sediment and paint waste samples. As shown on the two graphs on the left side of Figure I-2 (Appendix I), there are distinct differences in the distribution of PAHs in paint waste versus the PM Air Shaft sediment sample**.** Several 5- and 6- ring PAHs, compounds that are quite resistant to degradation, were detected in the PM Air Shaft sediment sample but not in paint waste, demonstrating that these PAHs cannot be derived from paint waste. These PAHs include:

- benzo(b)fluoranthene
- benzo(k)fluoranthene

- dibenzo(a,h)anthracene
- indeno(1,2,3-cd)pyrene
- benzo(g,h,i)perylene.

In contrast, acenaphthylene was detected in paint waste, but not in PM Shaft sediment. If PAHs in sediment were derived from paint waste, acenaphthylene would be detected in sediment.

Since naphthalenes are the most readily degradable PAHs, ARCADIS conducted an additional analysis to evaluate the potential effects of degradation of PAHs. PAH distributions were compared for paint waste and the PM Air Shaft sediment sample, removing naphthalene and 2-methylnaphthalene from the profile to simulate potential effects of degradation that would deplete the more easily degradable compounds. As shown by the two graphs on the right side of Figure I-2, the distribution of PAHs in paint waste is remarkably different from the PM Air Shaft sediment sample when effects of degradation are accounted for.

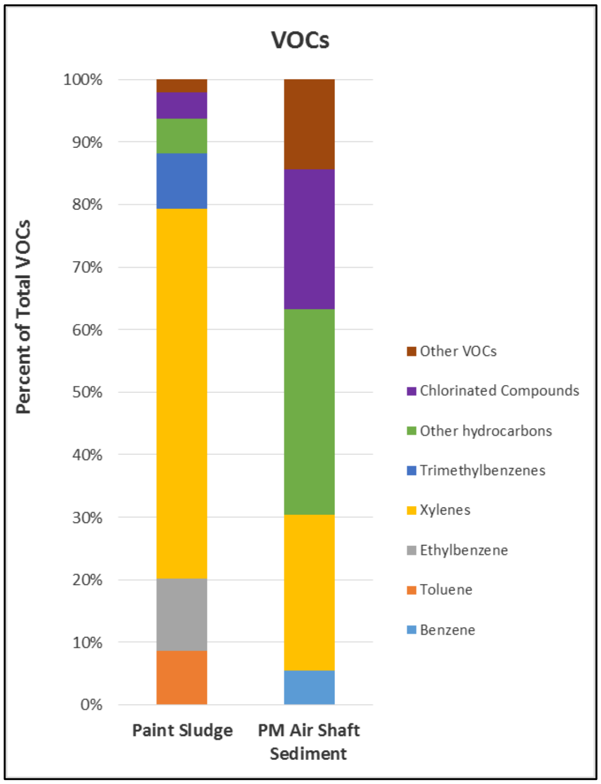
This additional analysis further supports the multiple lines of evidence contained in the forensics analysis and confirms the conclusion that the composition of PAHs in the paint waste is different from the composition of PAHs in the PM Air Shaft sediment, and therefore PAHs in sediment are not related to paint waste.

Given that the distribution of PAHs in paint waste samples is unique and completely different from that observed in sediment samples, ARCADIS conducted a multiple-regression mixing model to identify other possible source materials. This model predicts a PAH profile in the sediment sample consisting of a combination of 47% creosote and 53% combustion materials. Sources of these materials may include creosote-treated framing timbers used to stabilize mine shafts and adits, wastes from the historic mine fire, or emissions from generators used during mining operations. There is no plausible mixing scenario (paint waste plus another source) that can match the observed distribution of PAHs in the sediment sample.

VOCs

An additional line of evidence is derived from the VOC data. VOCs are highly susceptible to degradation (relative to PAHs), and can be more challenging from a forensics analysis perspective than metals and PAHs. However, when considering the type and relative abundances of key VOCs that are present in paint waste and PM Air Shaft sediment samples, conclusions can be made. The forensics analysis provided a baseline comparison of VOCs in paint waste and sediment samples, and demonstrated that the distribution of VOCs in the sediment sample was remarkably different, and not consistent with the VOC distribution in paint waste samples.

Degradation can cause shifts in VOC compositions and relative concentrations, but degradation cannot account for the differences in the distribution of individual VOCs in the paint waste samples compared to the sediment sample. To demonstrate this, ARCADIS completed this supplemental analysis to further evaluate VOCs and potential effects of degradation.



As presented in Figures I-3 and I-4 (Appendix I), the distribution of VOCs is clearly different for the PM Air Shaft sediment sample in comparison to the paint waste samples. In particular, individual VOCs were detected in the paint waste samples that were not detected in the PM Air Shaft sediment sample. These VOCs include:

- trimethylbenzenes
- ethylbenzene
- toluene
- tetrachoroethene
- trichloroethene
- cis-1,2-dichloroethene
- trans-1,2-dichloroethene
- 4-methyl-2-pentanone

In contrast, several VOCs were detected in the PM Air Shaft sample that were not detected in the paint waste samples including:

- trichlorobenzene
- dichlorobenzenes
- chlorobenzenes

Degradation cannot account for these profound differences in VOC distributions in the paint waste samples and the sediment sample, indicating that VOCs detected in the sediment sample are not associated with paint waste.

The effects of degradation were considered in more detail for the common VOC benzene and its companion VOCs toluene, ethylbenzene, and xylenes, collectively referred to as BTEX. Benzene and toluene degrade more readily than ethylbenzene and xylenes (Kaplan et al. 1997) under both aerobic and anaerobic conditions. Therefore, degradation will result in a depletion of benzene and toluene relative to ethylbenzene and xylenes, and we would see lower relative proportions of benzene and toluene to ethylbenzene and xylenes in the site samples. However, site-specific data reveal a different scenario:

- For paint waste samples, benzene was either not detected or was minimally detected (trace levels). Benzene accounted for an average of 0.02% total BTEX (with a maximum of 0.15% total BTEX).
- For the PM Shaft sediment sample, benzene accounted for 18% of total BTEX.
- For paint waste samples, toluene and ethylbenzene were detected in every paint waste sample analyzed for VOCs. Paint waste samples contained toluene ranging from 0.4% to 20.3% total BTEX with an average of 10%, and ethylbenzene ranged from 5.2% to 18.3% total BTEX with an average of 13.6%.
- For the PM Air Shaft sediment sample, toluene and ethylbenzene were not detected.

COC	**Paint Waste** (% total BTEX)[1]	**Sediment** (% total BTEX)
Benzene	0.02%	18%
Toluene	10%	ND
Ethylbenzene	13.60%	ND

ND = not detected

[1]Average % (Range of values provided in text)

If BTEX in the PM Air Shaft sediment sample was derived from paint waste, then benzene should be depleted relative to ethylbenzene (as observed in the paint waste samples). However, this is not the case. Rather, we find the opposite, where we observe an abundance of benzene in the sediment as compared to the paint waste samples and no detectable concentration of ethylbenzene in the sediment sample.

In conclusion, the chemical composition of paint waste samples and the sediment sample is distinctly different with respect to metals, PAHs, and VOCs. Degradation cannot account for the observed differences between the distributions of metals, PAHs, and VOCs in the paint waste samples compared with the PM Air Shaft sediment sample. The supplemental information provided herein supports the multiple lines of evidence contained in the forensics analysis demonstrating that the chemical composition of the PM Air Shaft sediment sample is different from paint waste and the PM Air Shaft sediment sample and paint waste are not related.

5.3.5 PMP Area Groundwater Results

Groundwater results from 2004 through 2014 are presented in Table 13 and are summarized in Figures 16 through 18 noting where concentrations of the primary COCs exceed the GWQS. Groundwater analytical results generated during the RI for the PMP Area demonstrate the following:

- TCL VOCs - There have been limited detections of benzene at concentrations above the GWQS of 1.0 µg/L in groundwater in the PMP and the PMP Area over the course of nine years of routine groundwater monitoring at the Site. The maximum concentration of benzene in overburden, shallow and deeper bedrock groundwater was 88.1 µg/L reported in 2014 at shallow bedrock well RW-6A. The benzene concentration in groundwater at well RW-6 also increased from 2.3 µg/L in 2013 to 15.7 µg/L in 2014. The previous maximum benzene concentration was 15.0 µg/L at well RW-6 in 2013.

- Note that, prior to 2013, the highest reported benzene concentration in the overburden groundwater was 6.5 µg/L at overburden well OB-27 in 2011. Benzene was reported at a concentration of 2.6 µg/L in groundwater at well OB-27 during the most recent sampling event in September 2014.

- The results of the 2014 monitoring event reported that the benzene concentration in groundwater at well SC-01 located in the PMP Pit increased from 1.6 µg/L in 2013 to 56.0 µg/L, howeverl well SC-01 was resampled in October 2014 to verify this result. The results of the 2014 sampling event confirm that the benzene concentration was 1.6 µg/L which is consistent with the historically low concentrations reported at this well location.

- Temporally elevated benzene concentrations, or “spikes”, were reported in the groundwater samples collected from monitoring wells SC-01 and RW-6A during the September 2014 sampling event. These “spikes” appeared to be outliers with respect to the preponderance of the groundwater analytical data set for the Site; therefore, after consultation with USEPA, these wells, along with overburden well OB-20B and bedrock well RW-6 (sampled as control points) were re-sampled in October 2014 to further evaluate the September 2014 outlier data.

- As anticipated, the October 2014 groundwater analytical results for benzene at all four of the wells that were resampled were consistent with historical benzene concentrations, including those historically reported in groundwater at wells SC-01 and RW-6A.

- The benzene “spikes” reported in September 2014 were further evaluated by reviewing the data validation report for wells SC-01 and RW-6A, including having the analytical laboratory verify the calculations and that the groundwater samples were logged into the lab as having elevated VOCs when screened prior to analysis, which they were. The field notes and sampling procedures for these wells were also carefully checked to ensure there was no indication of any field contribution to the reported benzene concentrations which there is no indication of. In addition, the concentrations of other trace VOCs and metals typically reported in groundwater samples collected from wells SC-01 and RW-6A were checked to ensure that they were consistent with historical sampling events which they were. The results of this supplemental evaluation indicate that the benzene “spikes” reported in September 2014 are data outliers;

therefore, these outliers were not considered in the benzene trend analysis provided in Section 5.3.9.

- TCL SVOCs - Prior to 2011, bis(2-ethylhexyl)phthalate was the only SVOC sporadically detected at concentrations above the NJDEP GWQS in groundwater samples from a limited number of bedrock wells. During the most recent sampling event in September 2014, the highest concentration was detected in RW-13 (59.3 µg/L), which is above the GWQS of 3 µg/L. In 2014, bis(2-ethylhexyl)phthalate was also detected above the GWQS in RW-5 (3.6 J µg/L) and RW-7 (6.6 J µg/L). The concentration of bis(2-ethylhexyl)phthalate was below detection limits at RW-10A in 2013 and 2014 after concentrations of 156 µg/L and 6.8 µg/L in 2011 and 2012. The concentration of bis(2-ethylhexyl)phthalate was below detection limits in RW-3DD in 2013 and 2014 after a concentration of 3.3 µg/L in 2012.

- Pesticides and PCBs - No pesticides or PCBs have been detected in overburden or bedrock groundwater samples collected during any of the sampling events conducted during the course of the RI.

- TAL Metals - With respect to TAL metals, the RI groundwater analytical results indicate the following:

  - Iron and Manganese – Total (unfiltered) and dissolved (filtered) iron and manganese have been detected at concentrations above their respective NJDEP GWQS in overburden and bedrock groundwater, with elevated concentrations in most of the groundwater samples collected from the overburden and bedrock monitoring wells located within and downgradient of the PMP and within the PM Air Shaft. Historically, background concentrations of iron and manganese exceed the GWQS at wells located upgradient of any of the land ACs, including well RW-7 located upgradient of the PMP. The September 2014 iron concentration in RW-7 was 1,430 J µg/L.

    - Elevated concentrations of dissolved iron and manganese generally correspond with areas where moderately to strongly reducing geochemical conditions occur in overburden and bedrock groundwater since these conditions cause these metals to be more soluble.

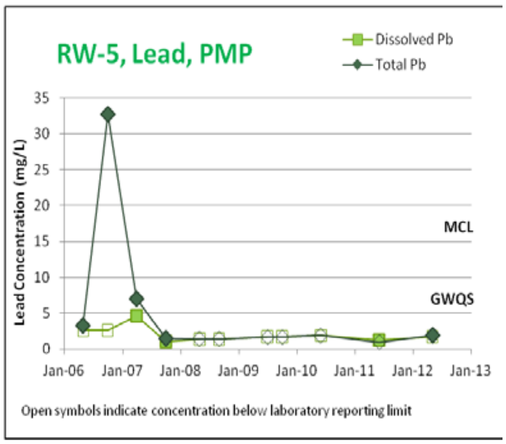
    - Reducing conditions may be maintained by microbial degradation of organic matter in the fill materials below the water table in the PMP. Organic matter may include wood, leaves, paper, and other detrital material in the PMP as well as trace VOCs and possibly SVOCs .

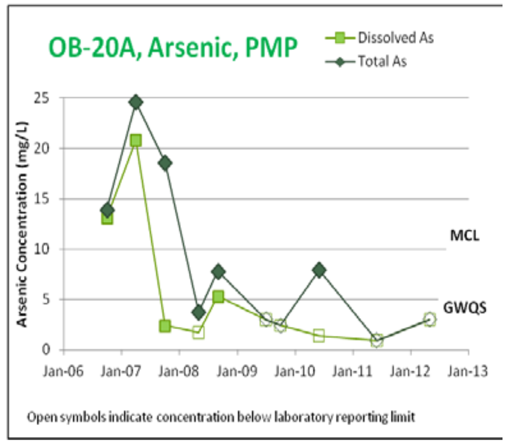
- Aluminum – Total (unfiltered) aluminum has historically been sporadically detected above the GWQS of 200 µg/L downgradient from the PMP in groundwater at overburden wells OB-15B, OB-20A, OB-27,OB-30B, and OB-30C and at bedrock wells RW-4, RW-5A, RW-5, RW-11D, and RW-13. In 2014, the concentrations in these wells ranged from 213 µg/L to 29,200 µg/L. Total (unfiltered) aluminum was also detected above the GWQS at upgradient overburden well OB-21 at a concentration of 1,350 J µg/L (2,350 J µg/L in duplicate) in 2014 and at upgradient bedrock well RW-7 at a concentration of 2,200 J µg/L. Dissolved (filtered) aluminum was detected above the GWQS in one overburden well sample collected at OB-30C (622 µg/L) in 2012, but was below the GWQS in 2013 and 2014. Dissolved aluminum was reported above its GWQS of 200 µg/L in bedrock wells RW-3DD, RW-4, RW-7, and RW-11D with concentrations ranging from 224 to 1,240 µg/L in 2014.

- Lead – From 2006 to 2013, total (unfiltered) lead has been detected above its GWQS of 5 µg/L at well SC-01 at concentrations ranging from 5.4 to 9.9 µg/L, but lead was not reported above its 5 µg/L GWQS in samples collected in September and October 2014. Lead has also been detected in downgradient overburden wells OB-11R and OB-20A and upgradient bedrock well RW-7 with historical concentrations ranging from 1.9 to 11.2 µg/L. Dissolved (filtered) lead was not detected at concentrations above the GWQS.

Note that the observed effect of redox on metals concentrations is augmented by the influence of turbidity on the detected concentrations of metals in groundwater samples. For example, with respect to lead, the sample collected from bedrock well RW-5 during the October 2006 event had a total lead concentration of 32.7 µg/L, whereas lead was not detected in the filtered sample. The unfiltered turbidity of the sample was 22.9 NTUs. The sample from well OB-20A collected during the October 2007 event had a detected total arsenic concentration of 18.6 µg/L as shown in the right graph on the following page, but only 1.5 µg/L of arsenic was detected in the filtered sample (with arsenic also present in blank). The unfiltered sample turbidity was 38.5 NTUs.

As low flow sampling techniques were approved for use at the Site in 2007 and efforts to reduce sample turbidity have resulted in lower total (unfiltered) and dissolved (unfiltered) lead and arsenic concentrations as illustrated in the graphs on the following page. Even with the use of low-flow sampling, however, turbidity is occasionally elevated and the target turbidity of 5 to 10 NTUs is not always achieved. Therefore, sample turbidity should always be checked and considered when detected concentrations of lead or arsenic exceed the GWQS due to the possibility that the reported concentrations may be biased high because of elevated turbidity. As previously discussed in Section 4.6.6, the analytical results generated using alternate USEPA Method 7062 indicates that arsenic is not detected, or is present at trace concentrations less than the detection limit, in filtered samples. The findings of the supplemental evaluation of arsenic conducted as part of the RI indicates that arsenic reported in groundwater in the overburden occurs due to sorption on particles and reported concentrations are biased high due to interference from REEs and/or are driven by elevated turbidity.





5.3.6 Peters Mine Air Shaft Groundwater Results

Groundwater analytical results for samples collected from the PM Air Shaft have generally been consistent during the period from 2006 through 2014 and the results indicate the following:

- Benzene is the only VOC detected in the PM Air Shaft groundwater samples at concentrations above the NJDEP GWQS of 1.0 µg/L. Benzene has not been detected in groundwater samples collected at a depth of 50 feet bgs.

  - Benzene concentrations ranged from non-detect to a maximum of 26.4 µg/L in groundwater samples collected from a depth of 180 feet bgs.

  - With the exception of the May 2012 (non-detect) and July 2009 (7.6 µg/L) sampling events, benzene was detected at concentrations ranging from 26.4 µg/L to 33.2 µg/L with an average of approximately 31 µg/L in groundwater samples collected from the base of the air shaft at a depth of 230 feet bgs.

- SVOCs and PCBs were not detected at concentrations above their respective GWQS in groundwater samples collected from depths of 50, 180, and 230 feet bgs, with the exception of bis(2-ethylhexyl)phthalate detected at concentrations of 3.4 µg/L and 3.5 µg/L for samples collected at depths of 180 feet and 230 feet bgs, respectively, in October 2009 and at 39.2 µg/L at 230 feet bgs in September 2014. With respect to TAL metals, iron and manganese concentrations have historically exceeded the NJDEP GWQS of 300 µg/L and 50 µg/L, respectively in the unfiltered and filtered samples collected in the PM Air Shaft at 180 feet and 230 feet bgs.

  - Elevated concentrations of dissolved iron and manganese generally correspond with moderately to strongly reducing geochemical conditions, which have been documented at the 230 feet bgs depth interval and periodically at the 180 feet bgs interval, since these conditions cause these metals to be more soluble. Moderately to strongly reducing conditions are demonstrated by low DO concentrations and low (e.g., negative) ORP (measured as Eh) values (Tables 15A through 15E).

- Reducing conditions may be maintained by microbial degradation of organic matter in the PM Air Shaft. Organic matter may include wood, leaves, and other detrital material in the PM Air Shaft as well as trace VOCs and possibly SVOCs

5.3.7 PMP Area Surface Water Results

Surface water samples were collected from the pond within the PMP on November 28, 2006 in the vicinity of each of the three former staff gauge locations designated SG-1 through SG-3 shown in Figure 3. The PMP pond surface water analytical results indicate the following:

- TCL VOCs, PCBs, and pesticides were not detected above laboratory reporting limits.
- Bis (2-Ethylhexyl)phthalate was detected at 9.3 µg/L (above the SWQS of 1.2 µg/L) in 2011.
- With respect to TAL metals, the data indicate the following:
  - Neither total nor dissolved lead was detected above the SWQS of 5.0 µg/L.
  - Neither total nor dissolved arsenic was not detected above the laboratory reporting limits.
  - Total iron was detected at concentrations above the 5 µg/L GWQS (iron has no SWQS) in unfiltered samples but was not detected in dissolved (filtered) samples. These results indicate that iron is present in the low solubility oxidized form (ferric iron, Fe^{3+}).
  - Total manganese was detected at concentrations above the 50 µg/L GWQS (manganese has no SWQS) in unfiltered samples, ranging from 377 µg/L to 555 µg/L. Dissolved manganese results were lower in concentration, ranging from 169 µg/L to 293 µg/L.

As shown in Figures 16A, 17A, and 18A for surface water samples collected from streams adjacent to and downgradient of the PMP, including Park Brook, Peters Mine Brook, and North Brook, data generated during the RI indicate the following:

- TCL VOCs, SVOCs, PCBs, and pesticides were not detected above laboratory reporting limits in any of the surface water samples collected from Park Brook, Peters Mine Brook, or North Brook adjacent to or immediately downgradient of the PMP.

- For the TAL Metals

  - Concentrations of arsenic are consistently above the SWQS of 0.15 µg/L in all of the surface water samples collected in the PMP Area, with concentrations ranging from 0.35 to 0.65 µg/L, including monitoring location SW08/PAB-00 (0.45 µg/L and 0.5 µg/L) located upgradient of the PMP Area. These results indicate arsenic is present in upgradient (background) surface water. In addition, concentrations of arsenic in surface water in the PMP Area are similar to upgradient background concentrations, indicating limited contributions of arsenic to surface water from the PMP Area.

  - Concentrations of thallium have been detected above the SWQS of 0.24 µg/L in surface water samples collected at SW-11 (0.85 µg/L) and SW-PAB-01 (0.28 µg/L).

For groundwater seep sample locations in the PMP Area, the data generated during the RI indicate the following:

- Benzene was detected in samples collected at the former paint waste removal area SR-3 seep at concentrations of 1.2 µg/L, 0.48 µg/L, and 0.85 µg/L, respectively, during the May 2010, May 2011, and May 2012 sampling events.

- For TAL metals, total (unfiltered) iron and manganese were detected in surface water samples collected at the SR-3 seep during the 2010 sampling event at concentrations of 19,400 µg/L and 420 µg/L, respectively, at concentrations of 21,500 µg/L and 477 µg/L, respectively, during the May 2011 event, and at concentrations of 24,900 µg/L and 539 µg/L, respectively, during the 2012 sampling event.

- The presence of benzene coupled with elevated concentrations of iron and manganese in the seep sample collected within SR-3 suggests that these constituents may be derived from groundwater originating in the PMP Area, flowing through the overburden, and discharging at the SR-3 seep.

The analytical results generated by PMP pond sampling indicate that the majority of constituents were not detected in sediment samples collected from the PMP pond. Of the constituents detected, PCB Aroclor 1260 and bis(2-ethylhexyl)phthalate were the only organic compounds exceeding an LEL screening value. Several metals exceeded their respective LELs in one or more samples, including antimony, arsenic, cadmium, copper, lead, nickel, and zinc. Arsenic exceeded the LEL and SEL screening levels in five out of six sediment samples and was the only constituent to exceed a SEL value.

5.3.8 Sediment Pore Water Investigation Results

Sediment pore water samples were collected from two locations (PZ-C and PZ-D) within Park Brook in August and September 2014 as shown on Figure 3. The results of the 2014 sediment pore water sampling are presented on Table 16.

The analytical results of sediment pore water samples collected at PZ-C and PZ-D indicated that VOCs were not detected above laboratory method detection limits in either of the two pore water samples. The samples were collected during extreme base flow conditions (dry stream bed) which is indicative of groundwater underflow conditions. These pore water analytical results confirm the conclusions made based on the preponderance of groundwater and surface water data generated during the RI that benzene in groundwater is not discharging to the surface water of Park Brook at either location located adjacent to and downgradient of the PMP Area.

5.3.9 PMP Area Groundwater Benzene Trend Analysis

The trend analysis consisted of linear regression, Mann-Kendall, and Sen's slope trend testing for groundwater benzene concentrations using available analytical data. Trend tests were completed for monitoring locations where benzene has been historically detected in groundwater. Linear regression, Mann-Kendall, and Sen's slope analyses using natural log (ln) normalized concentration data were used to estimate trend direction and significance of the trend. For locations that exhibited decreasing concentration trends, attenuation half lives and approximate timeframes to achieve screening levels were estimated using linear regression and Sen's slope trend results (Helsel and Hirsch 1995, USEPA 2002). In this evaluation, the screening level for benzene was set as equal to the GWQS of 1 µg/L. The benzene concentrations reported in groundwater samples collected at wells SC-01 and RW-6A in September 2014 are considered outlier data and were not used in this trend analysis. The analytical results from the resampling event in October 2014 were therefore used.

Linear regression analysis results include coefficient of determination (R^2), p-value of the correlation, trend direction and significance, attenuation rate, and estimated time for benzene concentration to meet the screening level if benzene concentrations are above the screening level (Table 17). Detailed analysis results for each monitoring location included in the linear regression trend analysis are included in Appendix J. The R^2 is a measure of how well the linear regression curve fits the site data; values close to one are considered to be a good fit (less scatter in data), while values close to zero are considered to be a poor fit (more scatter in data). Linear regression curves with R^2 values of less than 0.15 were considered to have too poor a fit for a trend to be determined, and were described as having no apparent trend. The p-value of the correlation provides a measure of the level of significance of the statistical test. Correlations were accepted as statistically significant for p-values less than or equal to 0.1, and not statistically significant for p-values greater than 0.1. The trend direction was defined as decreasing if concentrations decreased with time (benzene concentrations with time have a negative slope), and increasing if concentrations increased with time (benzene concentrations with time have a positive slope). Attenuation half lives were estimated for all decreasing benzene concentration trends.

Mann-Kendall analysis results include test statistic (sum of trend, S), p-value of the correlation, and trend direction and significance (Table 17). The Mann-Kendall trend test is a non-parametric test that determines trends based on ranked data, which can be useful where large variations in the magnitude of concentrations may be present and otherwise influence a time-series trend analysis. The basic Mann-Kendall trend test involves listing the concentrations in temporal order and computing all differences that may be formed between a given measurement and earlier measurements. The S value is the difference between the number of strictly positive differences and the number of strictly negative differences. If there is an underlying decreasing trend, then these differences will tend to be negative, indicated by a sufficiently large negative value of the test statistic. The p-value of the correlation provides a measure of the level of significance of the statistical test. Correlations were accepted as significant for p-values less than or equal to 0.10 (90 percent confidence level).

Sen's slope analysis results include the slope of the trend, the upper and lower 90% confidence level for the trend, trend direction and significance, and benzene attenuation rate (Table 17). The Sen's slope test is a non-parametric test that involves computing slopes for all pairs of time points and then using the median of these slopes as an estimate of the overall slope. This trend test is insensitive to outliers (Helsel and Hirsch 1995). The Sen's slope test was also evaluated at the 90 percent confidence interval for the median of the slopes. Where equal numbers of positive and negative differences were detected, the slope is defined as no trend. Attenuation half-lives were estimated for all decreasing benzene concentration trends.

Where non-detected or qualified values were used in computations, the concentrations were set equal to the laboratory reporting limits or reported value, where available. Use of the laboratory reporting limit for concentrations that were below detection provides a conservative estimate for evaluating the concentration trends through time. Generally a minimum of five data points is recommended to complete trend analyses; and all monitoring wells evaluated have at least five data points.

Results of the linear regression analysis indicated decreasing benzene concentration trends for four of nine groundwater monitoring locations where benzene has historically been detected (Table 17). Statistically significant decreasing trends in benzene concentrations were demonstrated for monitoring locations OB-20A, OB-20B, and OB-27. Decreasing, but not statistically significant trends in benzene concentrations were observed for monitoring well location OB-11/11R. No trend in benzene concentration was observed for monitoring well locations RW-6, SC-01, PM Air Shaft (180-foot depth), and PM Air Shaft (230-foot depth). An increasing trend that is not statistically significant is noted at the monitoring well RW-6A location. For monitoring well locations with decreasing benzene concentration trends, estimated benzene attenuation half lives ranged from 1,216 to 5,934 days.

Based on half lives estimated from the linear regression results, benzene concentrations were projected to reach screening levels in groundwater at OB-27 in 2019. Benzene concentrations at OB-20A have been below the screening level during the entire monitoring period while benzene concentrations were below the screening level at OB-20B since May 2011. Concentrations of benzene in groundwater at SC-01, completed within the PMP, have been below the screening level for five of the past nine monitoring events.

Mann-Kendall trend analysis results were similar to the linear regression trend analysis results (Table 17). Statistically significant decreasing trends were observed for OB-20A, OB-20B, OB-27 and RW-6. Decreasing but not statistically significant trends were observed for OB-11/11R, and PM Air Shaft (180-foot depth), and no trend was observed for PM Air Shaft (230-foot depth). Increasing trends were noted for SC-01 and RW-6A.

Sen's slope trend analysis results were similar to the linear regression and Mann-Kendall trend analysis results (Table 17). Statistically significant decreasing trends were observed for OB-20A, OB-20B, OB-27, and RW-6. A decreasing but not statistically significant trend was observed for OB-11/11R, PM Air Shaft (180-foot depth) and no trend was observed for PM Air Shaft (230-foot depth). Increasing trends (not statistically significant) were noted for SC-01 and RW-6A. Estimated benzene attenuation half lives were similar to half lives estimated using linear regression results and ranged from 1,155 to 6,930 days.

In summary, results from the benzene concentration trend analyses demonstrate statistically significant decreasing to decreasing trends at most groundwater monitoring locations in overburden where benzene has historically been detected. Where noted, increasing trends were not statistically significant. Consistent with SIP and Bio-Trap® results (Section 6), these trend analysis results indicate that natural attenuation of benzene is occurring in site groundwater.

5.4 2012 Vapor Intrusion Evaluation

An evaluation of groundwater analytical results with respect to vapor intrusion showed that benzene was the only VOC to exceed its NJDEP generic vapor intrusion Groundwater Screening Level (GWSL) of 20 µg/L (changed from 15 µg/L as of January 16, 2013). Note, however, that the exceedance of the benzene GWSL occurs in the PM Air Shaft at depths of greater than 180 feet bgs and not at any monitoring well location at the Site. There are no structures that exist within 100 feet of the PM Air Shaft; therefore, there is no vapor intrusion issue. Also, there is at least a 50-foot column of groundwater within the shallower portion of the air shaft where benzene is not detected. Therefore, no further evaluation or investigation of vapor intrusion is warranted at the Site.

5.5 Site-Related COC Occurrence and Distribution

The distribution of the three primary COCs that have been reported in overburden groundwater, and to a much lesser extent surface water, at the Site, specifically benzene, arsenic, and lead, is shown on Figures 16A, 17A, and 18A with companion figures showing the distribution of these constituents in bedrock groundwater. Generalized cross-sections of the Site are also provided as Figures 19, 20, and 21 to illustrate the COC distribution within the PMP and CMP areas and the regional hydrogeologic conditions across the Site.

As shown in Figure 16A and Figure 19, benzene is reported primarily in overburden and shallow bedrock groundwater in the immediate vicinity of the PMP Area, predominantly downgradient of the PMP with higher, but still slight, concentrations reported either in wells immediately downgradient of the Pit as well as at the base of the PM Air Shaft. As previously discussed in Section 5.3, the results of the RI indicate that the benzene concentrations at the base of the PM Air Shaft are isolated and benzene has not been detected in the surface water, or sediment pore water of Park Brook adjacent to the PMP Area. Although trace concentrations of benzene have been reported in one of the two groundwater seeps in the vicinity of the SR-3 Area located downgradient of the PMP, benzene has never been detected in groundwater in the OCDA located immediately downgradient of this seep or in the adjacent Park Brook surface water or sediment.

With respect to the CMP Area, benzene was only reported in 2009 but was attributable to sampling equipment and, based on the November 2013 groundwater monitoring event, a slight exceedance of the 1 µg/L benzene GWQS was reported at one bedrock well location (RW-8) at a concentration of 2.2 J µg/L. Well RW-8 is the only well location where trace benzene was detected in 2013 and 2014 (0.58 µg/L) and its occurrence during this sampling event is clearly anomalous in comparison to the historical data for this well and the CMP. Benzene has never been detected beyond the CMP Area or in the adjacent Mine Brook and continued groundwater and surface water monitoring is anticipated to confirm these findings.

Total arsenic has been sporadically detected above its 3 µg/L GWQS in overburden and shallow bedrock groundwater and surface water in the immediate vicinity of the PMP Area, OCDA, and CMP Area, however, the detections are isolated in occurrence and do not occur beyond the immediate vicinity of these areas. Arsenic has not been detected at downgradient monitoring well locations or in the lower reaches of the surface waters that traverse the Site. The results of the RI indicate sporadic detections of total arsenic at some of the deeper bedrock wells in the PMP and CMP Areas and generally at locations where groundwater geochemical conditions are reducing. These sporadic exceedances are slight in concentration and limited in their occurrence and distribution.

As described in Section 4.6.6, arsenic was not detected or was detected at trace concentrations in overburden monitoring well samples analyzed using USEPA Method 7062 during the September

2014 groundwater sampling event. The data indicate that REEs are causing biased high results results in groundwater at well locations where dissolved REEs are likely to occur, including in the vicinity of the mine pits located in the PMP and OCDA Areas.

Total lead has also been sporadically detected in overburden groundwater and, to a lesser extent, in surface water most often in the immediate vicinity of the PMP Area and OCDA, with a significantly lesser frequency of detection in groundwater and surface water in the CMP Area. When exceedances have been reported, the total lead concentrations are typically just above its 5 µg/L GWQS and the occurrence and distribution is sporadic and isolated. Surface water detections of lead are also sporadic and limited to the immediate vicinity of the land AC. Over the course of the groundwater RI, total lead was detected in 2005 in only one surface water sample from Park Brook near Sally's Pond as shown in Figure 18A, however, subsequent rounds of sampling since that time have confirmed that lead is not reported above its applicable criterion. Total lead has been sporadically reported above its 5 µg/L GWQS in bedrock groundwater only in the PMP Area and its occurrence and distribution is limited to the immediate vicinity of the PMP with no lead reported in groundwater at any of the downgradient bedrock well locations south or east of the Site.

The results of the RI therefore indicate that the COCs reported in groundwater at the Site are localized to the immediate vicinity of the PMP and to a much lesser extent the OCDA and CMP Area at concentrations that are variable but, when and where they exceed their respective GWQS, the exceedances are slight with no migration beyond the boundaries of the land ACs or the Site. It is fully anticipated that the results of future groundwater and surface water monitoring will confirm these findings.

6. Groundwater Flow, Connectivity, and Attenuation Evaluation

Supplemental groundwater investigation activities were conducted from April through August 2012 in accordance with the Proposed Supplemental Site-Related Groundwater Remedial Investigation Work Plan (ARCADIS 2012a) to characterize groundwater flow pathways and connectivity between bedrock, overburden, surface water, and the PM Air Shaft and CM Shaft, and to further develop the CSM for the Site. The work scope for the Supplemental RI was developed to respond to correspondence and discussions between USEPA, NJDEP, and Ford regarding performance of a tracer study in the vicinity of the PMP and the CMP and as necessary to complete the RI of Site-related groundwater. The USEPA approved the supplemental Work Plan in their August 15, 2012 correspondence.

Groundwater samples were collected from within the PM Air Shaft, the CM Shaft, and key groundwater and surface water monitoring locations for analysis of a wide range of parameters to provide data for an environmental tracer study. Together with supplemental groundwater and surface water elevation monitoring and geochemical and microbiological testing, the environmental tracer study enabled an in-depth evaluation of natural attenuation mechanisms that influence the occurrence, fate, and transport of various constituents in groundwater at the Site.

6.1 Flow Characterization

Ambient flow measurements were collected within the PMP and CMP Areas to supplement data generated during the previous years of monitoring at the Site. The flow measurements were taken within the PM Air Shaft and CM Shafts to evaluate whether there was groundwater flow within the shafts under non-pumping conditions and, if so, if it was upward, downward, or both. Geophysical Applications, Inc. performed the down-shaft logging in both the PMP and CMP in May 2012, which included the following fluid-properties: fluid temperature (FTemp), fluid conductivity (FCond), DO (O_2), pH, and ORP (or redox, measured as Eh). Variations in these fluid properties may represent hydraulically active zones. Spinner and heat-pulse flow meter probes were also used within both the CM Shaft and PM Air Shaft. A copy of the Geophysical Applications, Inc. report is provided in Appendix E.

In the PM Air Shaft, continuous flow measurements were collected from the top of the shaft to the base of the shaft at a depth of approximately 230 feet bgs. Flow measurements were also collected at discrete intervals, including a relatively shallow depth of 50 feet bgs and two deeper intervals where benzene has historically been detected in groundwater samples collected from the air shaft, including at depths of 180 and 230 feet bgs. Due to debris and obstructions within the CM Shaft, ambient flow measurements were limited to depths of up to 170 feet bgs. However, discrete flow characterization was conducted at depths of 50, 100, and 160 feet bgs.

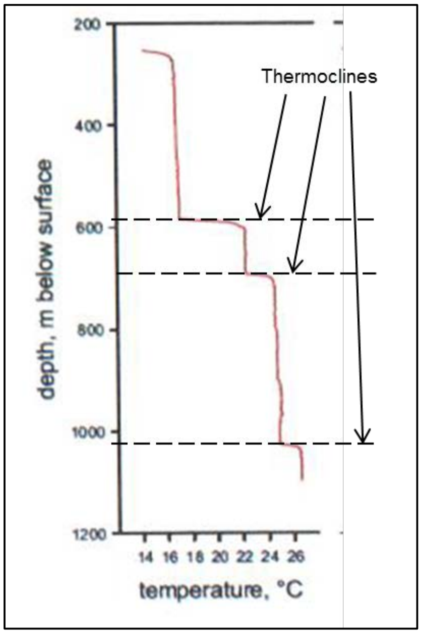
The flow evaluation was conducted using mechanical spinner flow meters and heat-pulse flow meters. Because of the large diameter of each shaft (20 by 20 feet for the PM Air Shaft and 10 by 10 feet for the CM Shaft) in comparison to a typical borehole or monitoring well, the meters could only be used as a qualitative indicator of flow in the shafts because the instrumentation could not be calibrated properly to account for the difference in diameter between the mine shafts and a typical 6-inch-diameter bedrock borehole.

Given the limitations of the groundwater flow evaluation, results indicated that the rate of groundwater flow was very low, on the order of less than 1 gpm, and that the groundwater flow was generally upwards from top to bottom with possible outflow of groundwater from the upper portions of the shafts.

In the vicinity of the CMP, upward vertical gradients were observed based on groundwater elevations for shallow bedrock well OB-1 and the deeper bedrock RW-1 well cluster (Figure 22A). The elevation of groundwater in the CM Shaft was approximately eight feet higher than the nearest shallow bedrock well OB-4, indicating an upward hydraulic gradient from deeper bedrock to shallow bedrock in the vicinity of the CM Shaft (Figure 22B). Downward vertical gradients were observed for groundwater in the vicinity of the CMP for wells OB-2 and RW-8S(163-173) towards well SC-02 (Figure 22C), suggesting that mine workings in the CMP Area act as groundwater drains, with drainage of groundwater towards surface water (Mine Brook).

The CM Shaft is completed to a total depth of at least 380 feet, where previous inspections were stopped due to shaft blockage. Within the CMP Area, the CMP and the CM Shaft are connected by tunnels and underground workings. Groundwater levels in the CMP at well SC-02 were typically greater than four feet higher in elevation than in the CM Shaft. Unlike the PMP Area where water levels were similar between the PMP well SC-01 and the PM Air Shaft, groundwater elevation data for the CMP Area indicate a horizontal gradient from the CMP towards the CM Shaft.

Horizontal hydraulic gradients were calculated for wells screened at similar depths within a given hydrologic unit. The horizontal hydraulic gradient between bedrock wells OB-4 and OB-5 in the CMP Area was 0.09 ft/ft toward the southeast, suggesting shallow bedrock groundwater discharges to Mine Brook. The ground surface topographic gradient between these two wells is 0.13 ft/ft, which is consistent with the calculated hydraulic gradient and indicates that groundwater flow is affected by topography in the CMP Area. The CMP Area is situated on a ridge and, based on measured groundwater and surface water elevations (Figures 22A through 22C and Figure 23), groundwater in the CMP Area flows towards Mine Brook, which is consistent with observations of groundwater seeps along the hillside slopes below the CMP. There does not appear to be as strong a hydraulic connection with deep regional bedrock groundwater in the CMP Area as observed in the PMP Area (Section 6.3).

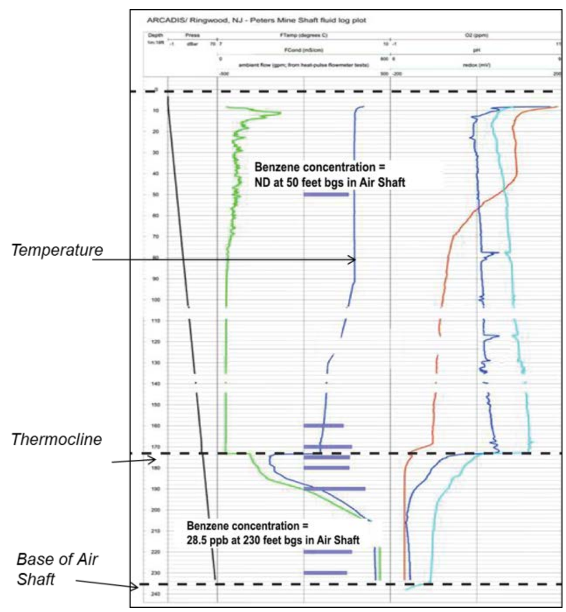


(Example of geophysical profile, taken and adapted from Water Management at Abandoned Flooded Underground Mines, Wolkersdorfer 2008)

An enhanced evaluation of the analytical data relative to flooded-mine hydraulic and hydrodynamic processes was conducted to further develop an understanding of the potential connectivity and flow regime of the water in the PM Air Shaft.

As discussed with the agencies, the flow meter analysis from inside the PM Air Shaft was determined to be unreliable given that the PM Air Shaft diameter exceeds the specifications for use of flow meters. However, the thermal and geophysical profiling conducted in the PM Air Shaft provides evidence of a thermal stratification at approximately 170-180 feet bgs. This can be seen by the break in slope along the temperature profile on the geophysical logs.

Referred to as thermoclines, these are common phenomena in flooded mine workings (Wolkersdorfer 2008) based on founded limnology principles. This kind of stratification can be stable in isolated/deep mine workings. The presence of a thermocline within the PM Air Shaft creates conditions that limit the physical mixing between the water above and below the depth of stratification, thereby providing a mechanism that inhibits migration of water and actively contains the benzene that is present in water at the base of the PM Air Shaft.



This area at the bottom of the shaft can be considered to be a "mine pool"- a stagnant zone of water commonly found in flooded mines that lack mechanisms to induce vertical flow. Given that the bedrock is known to be very competent at depth, with negligible lateral communication between the deeper shaft/mine workings and the surrounding bedrock aquifer, benzene--at low concentrations in groundwater-is contained and remains in an isolated layer of water at the bottom of the PM Air Shaft.

This chemocline is represented by changes in dissolved oxygen, iron, and manganese concentrations as well as changes in oxidation-reduction potential (ORP). This chemocline does appear to present an impediment to upward migration of benzene, as benzene was not detected at the 50-foot interval (three recent events: two in 2012 and one in 2014). The CSM shows this boundary condition as a layer with a transitional upper part so that the thermo/chemocline is not represented as a razor sharp line. At a depth of 180 feet, this mine pool feature, if existent through the subterranean parts of Peters Mine, is below the base of the Peters Mine Pit which is logical as the pit itself should act as a saturated zone area of mixing.

Although the data set has limits because the air shaft is the only direct sampling access to the mine pool, it is adequate to understand that a mine pool is present as flooded mines that have restricted outflow have mine pools. This is based on comparison to similar published data from mine pools in coal mines in Pennsylvania and hard rock mines in New England and the Rocky Mountains, such as the Elizabeth Mine Superfund Site in Vermont, Schwartzwalder Uranium Mine and Standard Mine in Colorado (USGS Open-File Report 2011-1092 and USGS Scientific Investigation Report 2007-5265), Huntsville Gob Mine in Missouri (Behm and Christensen, 2006), and virtually all abandoned coal mines in Pennsylvania and West Virginia that are below the water table (see West Virginia Mine Pool Atlas Project (USGS, Open-File Report 2014-1167) and Mine Water Resources of the Anthracite Coals Fields of Eastern Pennsylvania (EPCAMR 2011). The data set shows that the flooded parts of the Peters Mine are isolated to the extent that there is minimal interaction between water in the mine and the bedrock, however, it does indicate that water in the flooded mine has very limited interaction with the fractured bedrock especially with respect to the volume of water trapped in the mine and the volume of groundwater present in the bedrock. Note that the hydraulic conductivity of the fractured bedrock as presented by the yield of the site bedrock wells is very poor.

6.2 Surface Water Measuring Stations and Rain Gauge Installation

Surface water elevation monitoring was conducted to more accurately document the relationship and connections between groundwater and surface water at the Site. In accordance with the Supplemental RI Work Plan, the work scope included installation of eight surface water elevation measuring stations at the locations shown on Figure 3. The surface water elevation measuring stations consist of land-based surveyed pins from which water levels were manually measured with staff gauges.

As shown on Figure 3, the surface water elevation measuring stations were installed within surface water bodies within and/or adjacent to the PMP Area, the OCDA, and the CMP Area at locations that coincide with the location of surface water and sediment samples collected during the RI activities at the Site. Synoptic surface water level measurements were collected at the surface water elevation measuring stations twice a week over a 6-week period. The surface water measuring locations and elevation data are summarized in Table 19A of this RIR. Additional surface water elevation data collected in August through November 2014 are summarized in Table 19B of this RIR.

Note that the surface water elevation data were used in conjunction with the groundwater elevation data from key monitoring wells and from the PM Air Shaft and CM Shaft generated during the pressure transducer study component of the Supplemental RI discussed in Section 6.3 below for verification of groundwater to surface water discharge patterns, pathways, and connectivity.

6.3 Pressure Transducer Study

As part of the Supplemental RI, a total of 33 pressure transducers were installed in key monitoring wells located within the PMP and CMP Areas and within the PM Air Shaft and CM Shaft, for continuous monitoring and documentation of groundwater levels. The pressure transducers were maintained for a period of 8 weeks during the summer of 2012.

In the PMP Area, pressure transducers were deployed at 14 bedrock well monitoring locations, including wells RW-3, RW-3DS(155-160), RW-3DD(175-180), RW-4(333-343), RW-4(393-404), RW-4A(62-72), RW-4A(113-123), RW-5, RW-5A, RW-6, RW-6A, RW-7, RW-11S(236-241), and RW-11D(262-267); and at six overburden well locations, including angled well SC-1 within the PM pit, well SC-2 located within the CM pit, and PMP Area overburden wells OB-11R, OB-19, OB-20A, OB-20B, OB-21, and OB-27 (Figure 3).

In the CMP Area, pressure transducers were deployed into six bedrock wells, including wells RW-1(64-74), RW-1(131-141), RW-2(279-289), RW-2(452-462), RW-8(163-173), RW-8(204-214); and in five overburden wells, including wells OB-1, OB-2, OB-3, OB-4, and OB-5; and in the CMP pit well SC-2 and the CM Shaft (Figure 3).

In addition, as summarized in Table 19, a total of eight surface water gauging stations were installed within Park Brook, Mine Brook, Peters Mine Brook, and Peters Mine Pond and surface water levels were manually measured twice per week during a 6-week period during the summer of 2012. Water levels were converted to surface water and groundwater elevations by referencing measured elevations of gauge tops and tops of well casings to allow for direct comparison. Total daily precipitation levels measured at the Ringwood, New Jersey Remote Automatic Weather Station were compiled to assess recharge dynamics in groundwater and surface water. These data were used in lieu of site-specific rain gauges because they represent daily precipitation totals, where rain gauges are visited less frequently and only provide the total precipitation between site visits.

The data generated during the water level monitoring study confirm data from previous RI activities, which indicate that surface waters at the Site generally flow from north to south, changing directions locally according to bends in the brook channels. Surface water hydraulic gradients ranged from

0.01 to 0.05 ft/ft in the PMP and CMP Areas, respectively, and largely reflect changes in topography across the Site.

The data indicate that surface water levels in the most upgradient brook, Park Brook, responded rapidly to precipitation. For example, approximately 8.5 inches of precipitation over a 10-day period resulted in water levels increasing by approximately 0.8 foot between the July 17 and July 20 gauging events. Water levels at downgradient locations did not increase as significantly (approximately 0.3 to 0.7 foot) as the brooks widen, and ponds and wetlands serve to attenuate the effect of localized recharge on surface water elevations.

Based on the pressure transducer study conducted during the RI, groundwater elevations in both the overburden and underlying bedrock in the PMP Area responded rapidly to precipitation events, indicating that a limited storage volume is available in these water-bearing units. As shown in Figures 24A and 24B, water level responses were more rapid with larger magnitude changes in groundwater elevations in wells screened in the overburden than in bedrock. For example, the overall variation in overburden groundwater elevations during the study period was 0.9, 1.16, and 1.46 feet for wells OB-20B, OB-19, and OB-20A, respectively, while the variation in bedrock groundwater elevations was 0.55, 0.58, 0.62, and 0.76 foot for wells RW-6, RW-5A, RW-5, and RW-6A, respectively.

As shown on Figures 24A and 24B, the results of the transducer study in the PMP Area also confirm that groundwater elevations are generally highest in the PM Air Shaft and well SC-01 located in the PM pit and shallowest in overburden groundwater monitoring locations and for the PMP pond surface water, indicating the potential for some minimal upward vertical flow from deeper groundwater to shallow groundwater and ultimately to surface water. An upward vertical potentiometric gradient from deeper to shallower bedrock was also documented at the PMP Area well pairs completed in bedrock, wells RW-5A and RW-5; RW-6A and RW-6, and an upward gradient was documented from deeper overburden to shallower overburden at well pair OB-20A and OB-20B. The upward vertical hydraulic gradient between the overburden and bedrock ranged from approximately 0.01 to 0.04 ft/ft. Overall, the data indicate that there is potential for groundwater flow upward through the bedrock into the overburden with eventual possible discharge to surface water bodies with gaining conditions documented in Park Brook. However, well purging data demonstrate that the bedrock yield is very limited, indicating that while there is a potential for upward vertical migration of groundwater, the actual migration of deeper groundwater to shallow bedrock or overburden likely is also very limited.

As shown in Figures 25A and 25B, downgradient of the PMP at the bedrock well RW-3 and RW-4 well clusters, groundwater elevations decrease with depth indicating downward vertical gradients at these locations. These downward hydraulic gradients do not appear to be caused by their proximity to site features such as ponds, brooks, or air shafts and suggest that groundwater in bedrock at these locations may not be in hydraulic connection or communication with the underlying PMP mine workings.

Groundwater elevations at SC-01 in the PMP are generally higher than groundwater elevations at downgradient monitoring wells OB-19, OB-20A, OB-20B, RW-5A, RW-5, RW-6A, and RW-6 confirming the groundwater flow gradient from the PMP Area towards these wells. Horizontal hydraulic gradients were assessed for wells with similar screened depth intervals in a given water-bearing unit. The horizontal hydraulic gradient was generally toward the nearest brook and perpendicular to the topographic surface, indicating potentially gaining conditions for surface water throughout the PMP Area. As shown in Figures 23 through 25, this is supported by the surface water elevations in the PMP Area that are lower than groundwater elevations for wells located at similar topographic elevations.

The PM Air Shaft presently has a depth approximately of 232 feet bgs where it intersects some of the upper underground mine tunnels and workings. The inclined shaft that runs upward to the PMP and downwards towards deeper underground mine workings is approximately 50 feet below the present air shaft termination. Based on historical maps, drawings, and documentation of the mine workings, both the PMP and the PM Air Shaft are connected with the underground workings that extend to maximum total depths of approximately 1,700 feet bgs (measured from the slope of Hope Mountain). The underground mine working likely intersect deep regional bedrock groundwater that is under pressure, resulting in an upward groundwater potentiometric gradient where groundwater is in hydraulic connection with the upper part of the underground workings. The rate of water infiltration into the Peters Mine provided to Albert Getz (New Jersey Mine Safety Bureau) suggests a maximum dewatering rate of approximately 50 gpm, which indicates a very small rate of seepage from bedrock to the mine workings (Getz 1965).

During the transducer study conducted in 2012, the groundwater elevation in the PM Air Shaft was approximately two feet higher than in the nearest bedrock well included in the transducer study (RW-5A, screened from 54 to 74 feet bgs) and approximately 3 feet higher than the nearest overburden well (OB-19, screened 5 to 20 feet bgs) (Figure 24B). These results indicate an upward potentiometric hydraulic gradient is present, and that the PM Air Shaft has a limited hydraulic connection to deeper bedrock through the deeper underground mine workings, but may be less connected with shallower bedrock and overburden groundwater. Locations with downward vertical gradients, e.g., RW-3 and RW-4 well clusters, suggest that groundwater at these locations are not in hydraulic connection with underground workings.

6.4 Environmental Tracer Study

During the Supplemental RI, groundwater and surface water samples were collected at 32 locations within the PMP and CMP Areas, including the PM Air Shaft and CM Shaft, key overburden and bedrock monitoring well locations, and surface water locations as summarized in Table 6. A total of

52 groundwater and surface water samples were collected from the PMP and CMP as shown on Figures 6 and 7, respectively. Groundwater samples were collected from each sample location using the groundwater sampling and analytical procedures documented in the May 2004 and June 2009 project-specific QAPP (ARCADIS 2009c). Supplemental sampling procedures not included in the QAPP and analytical methods that differed from those established in the QAPP are summarized in the subsections below. Complete analytical data from the April, May, and June 2012 sampling events for all monitoring locations is provided in Appendix G.

As summarized in Table 6, the analytical scope of work sample analyses included a wide range of key geochemical parameters, including radioactive and stable environmental isotopes, and anthropogenic gases designed to enable an evaluation of the origin and estimated age of groundwater from different sources and, coupled with groundwater and surface water elevation and groundwater quality data, to verify groundwater flow and constituent migration pathways and the connection between groundwater in the bedrock and overburden and its relationship to surface waters at the Site. It was important to evaluate a wide range of parameters because the effectiveness of each method was unknown given the unique features of the Site. As described in more detail in the subsections below, the various methods used to estimate age of groundwater are not all conclusive, but valuable information was gathered:

- The results point to mixing of water that is hundreds to thousands of years old and modern water that was recharged from precipitation since circa 1940. In the mine workings, when pumping activities stopped, the shafts and mines filled predominantly with modern water. Because groundwater flow in bedrock is minimal, modern water markers in older water are typically muted. At locations that are further away from the mine workings, much older water is observed at depth with a more modern water signal typically observed progressing higher in the water column.

- There is some hydraulic connectivity between overburden, shallow bedrock, and mine pit groundwater, but a much more limited connectivity in deeper bedrock and deeper mine workings. Groundwater in the mine workings is relatively stagnant and there appears to be limited flow of groundwater from bedrock fractures into the pits. Connectivity between pit water and groundwater is greatest for monitoring wells completed within the upper 100 feet of overburden or bedrock at monitoring locations closest to the pits.

6.4.1 Carbon-14

The Carbon-14 (^{14}C) technique is an indirect method for age dating of water that is typically used to date groundwater that was recharged more than 60 years ago and relies on the presence of inorganic and organic carbon in the water. ^{14}C, or radiocarbon, is a radioactive isotope with a half-life of approximately 5,740 years. Measured ^{14}C concentrations are normalized to the international standard known as “modern carbon” and are reported as percent modern carbon (pmc). Measured

^{14}C concentrations must also be corrected for various dilution and fractionation effects (Clark and Fritz 1997).

Atmospheric concentrations of ^{14}C peaked during atmospheric testing of thermonuclear devices conducted during the 1950s and 1960s, resulting in potential pmc values greater than 100 percent. This influx of ^{14}C to the atmosphere complicates precise interpretation of ^{14}C ages for water with recharge occurring after 1952, which is the case at the Site. ^{14}C values greater than 100 pmc indicate that recharge occurred sometime after 1952, but the inferred, or apparent age, can only be reported as less than 60 years. In addition, mixing of older groundwater with groundwater recharge that has occurred in the past 60 years may result in an underestimate of groundwater age.

To evaluate for ^{14}C, 1 liter (L) of water was collected with no headspace for the analysis. Care was taken to avoid exposure of samples to fluorescent displays, and bottles were flushed with sample water prior to filling. Samples were shipped at ambient temperature in coolers according to standard chain-of-custody procedures to the Isotope Tracer Technologies, Inc. (IT^2) laboratory located in Waterloo, Ontario, Canada for accelerator mass spectrometry radiocarbon dating. The ^{14}C analytical results for groundwater and surface water samples are summarized in Table 20 and the data are provided in Appendix G. Data quality was acceptable and results were used directly for comparing the relative age of surface water and groundwater across the Site.

Findings - CMP Area

Results of the ^{14}C analysis for the CMP Area are summarized on Table 20 and are shown graphically on Figures 26 and 27. The data show the inferred ^{14}C, or radiocarbon, ages for surface water samples collected from the Peters Mine Brook and Mine Brook within the CMP Area ranged from less than 60 years at surface water sample SW-PMB-02 to 828 years at sample location SW-03. Surface water radiocarbon ages increased from upgradient sample location SW-PMB-02 of less than 60 years to downgradient sample location SW-03 of 828 years, indicating increasing contributions of older groundwater to surface water along the surface water flow path through the CMP Area.

Radiocarbon ages of groundwater within the bedrock exhibited significant variability generally reflective of the depth of the well with groundwater in deeper bedrock wells generally being older. Inferred ^{14}C groundwater ages ranged from less than 60 years at shallow bedrock well OB-5 to 8,938 years at the deepest bedrock well in the CMP Area, well RW-2 (452-462). Groundwater samples collected from depth intervals greater than 120 feet bgs had radiocarbon groundwater ages that were significantly older than in shallower bedrock, with ages ranging from 1,713 to 8,938 years. The younger radiocarbon ages in shallower bedrock groundwater reflect greater contributions of modern recharge.

Groundwater samples collected from within the CM Shaft had radiocarbon groundwater ages ranging from 410 years (at 275 feet) to 697 years (at 50 feet). These radiocarbon ages are similar to radiocarbon ages measured for shallow bedrock groundwater where ages ranged from less than 60 to 647 years for bedrock wells OB-1, OB-2, OB-3, OB-4, OB-5, RW-10A (51-61), and RW-10A (75-85). Monitoring well SC-02, within the CMP, had a radiocarbon age of 969 years, which is between radiocarbon ages observed in the shallower bedrock and the deeper bedrock.

These results suggest hydraulic communication between groundwater within the CMP, the CM Shaft, and CM-related underground workings. Water in these underground workings is comprised of a mixture of older groundwater from deeper bedrock, and younger groundwater from shallower bedrock and from modern recharge that occurred during infilling of underground workings after cessation of mining activities. Older groundwater, potentially from deeper bedrock, is discharging to surface water in the CMP Area. Discharge of deeper bedrock groundwater to surface water can occur because bedrock groundwater that is considered to be deeper within the CMP Area (e.g., greater than 100 feet bgs) is present at an elevation that is similar to surface water; i.e., the Mine Brook channel is approximately 125 to 150 feet lower than the land surface within the CMP Area.

Findings - PMP Area

Results of the ^{14}C analysis for the PMP Area are summarized on Table 20 and are shown graphically on Figures 28 and 29. Inferred radiocarbon ages for surface water samples collected from the PMP Area ranged from 24 years (SW-PAB-01) to 252 years (SW-PAB-00). Surface water radiocarbon ages generally decreased from the upstream Park Brook sample location SW-PAB-00 (252 years) to the downstream Park Brook sample location SW-PAB-02 (32 years). These data indicate contributions of older groundwater to surface water upstream of the PMP Area and increasing contributions of modern water (less than 60 years old) along the surface water flow pathway downstream of the PMP Area. Modern water may be contributed from precipitation runoff or from preferential migration of modern water through the overburden.

Groundwater samples collected from within the PM Air Shaft had radiocarbon groundwater ages ranging from 231 years at 180 feet to 468 years at the 50 feet bgs sample depth. Water within the air shaft at the shallowest interval exhibited the oldest radiocarbon age for that location. Radiocarbon ages of groundwater within the PMP Area overburden exhibited significant variability, ranging from less than 60 years at well OB-20B to 3,313 years at well OB-27. Similarly, radiocarbon ages of groundwater at PMP are bedrock monitoring wells ranged from less than 60 years at bedrock wells RW-4A (62-72) and RW-11S to 6,242 years at bedrock well RW-5A. Groundwater in the PMP (SC-01) had a radiocarbon age of less than 60 years.

The PM Air Shaft water has an “intermediate” age, which is most likely due to mixing of old water and modern water. The ages are unique and differ from nearby sampling points, indicating that there is limited connection between PM Air Shaft water and overburden and bedrock water.

Groundwater radiocarbon ages greater than approximately 100 years indicate significant contributions from bedrock groundwater that was recharged hundreds to thousands of years ago. The ^{14}C data for overburden and bedrock well locations in close proximity to the PMP indicate recharge of modern water may have occurred when underground mine workings were abandoned circa 1960 when dewatering operations ceased. At that time, older groundwater from the deep bedrock was allowed to fill the mines while water from modern recharge was introduced into the underground mine workings through surface opening including the PMP and the PM Air Shaft. This mixing of older bedrock groundwater with modern recharge has resulted intermediate radiocarbon age of water in the PM Air Shaft, and the range of groundwater radiocarbon ages observed in PMP Area groundwater.

Groundwater with the oldest radiocarbon ages (greater than approximately 1,000 years) are clustered within the center of the PMP Area at overburden wells OB-19, OB-20A, and OB-27 and bedrock wells RW-5, RW-5A, RW-3, and RW-3D. The older inferred groundwater ages at these overburden and bedrock wells are consistent with the upward vertical flow gradients documented at well pairs and clusters within the PMP Area with some older aged groundwater in bedrock less than 200 feet deep –mixing with the shallowest bedrock and then to the overburden and are likely representative of pre-mining conditions. Conversely, overburden groundwater at wells OB-20B and bedrock groundwater ages of less than 60 years as documented at wells RW-4A and RW-11S indicate an influence from, and connection with, a modern water source. Groundwater at overburden well SC-01 located within the fill material of the PMP pit has a radiocarbon groundwater age of less than 60 years indicating a modern source of water in the PM pit that is the likely source of modern water reflected at wells located downgradient of the pit.

6.4.2 Tritium

Tritium (3H) is a radioactive isotope with a half-life of 12.3 years. The tritium age dating technique offers a direct measurement of water age for modern waters with recharge dates in the past 60 years. Tritium activities are expressed as absolute concentrations in tritium units (TUs) and no reference standard is required.

The concentration of tritium in groundwater reflects the atmospheric concentrations of tritium at the time when the water was recharged, although mixing with older tritium-free water will dilute the measured tritium concentration. Prior to the start of atmospheric testing of thermonuclear devices in the early 1950s, tritium concentrations in precipitation water ranged from approximately 2 to 8 TUs. Atmospheric tritium concentrations increased during the 1950s and peaked in about 1963, but have been continually declining since this peak. In 2012 when the Supplemental RI was conducted, atmospheric tritium concentrations had returned to original background concentrations at most tritium monitoring locations around the world. Therefore, quantitative ages are difficult to determine based on tritium data alone. However, qualitative interpretations of tritium data are possible (Clark and Fritz 1997; Divine and Humphrey 2005).

For continental regions, Clark and Fritz (1997) proposed the following ranges in tritium concentrations to qualitatively assess groundwater ages. Since these values were published approximately 15 years ago, updated proposed tritium ranges that account for additional tritium decay are provided in parentheses:

- less than 0.8 TU (less than 0.4 TU): Submodern (prior to 1952)
- 0.8 to 4 TU (0.4 to 2 TU): Mixture of submodern and recent recharge
- 5 to 15 TU (2 to 7 TU): Modern recharge (between 5 and 10 years ago)
- greater than 30 TU (greater than 15 TU): Considerable component of recharge is from the 1960s or 1970s
- greater than 50 TU (greater than 25 TU): Dominant source of recharge is from the 1960s

Interpretation of tritium results may be difficult for groundwater samples that contain a mixture of modern (post-1952) water with detectable concentrations of tritium and water that was recharged more than 100 years ago that does not contain tritium, as dilution of the modern tritium signal will occur. Tritium concentrations in precipitation are seasonally variable, with a maximum concentration typically occurring in spring and summer, and a minimum in winter. The current 10-year average for the United States (USEPA 2012) for tritium concentrations in precipitation is 7.2 TU, while the 10-year average for USEPA Region 2 is 8.4 TU.

To evaluate for tritium, 1 L of water was collected with no headspace using the same sample collection and handling procedures as ^{14}C. Samples were analyzed for tritium content at IT^2 located in Waterloo, Ontario, Canada using Method TP 1.0 Rev.02.

Findings

Results of the tritium analysis for the CMP Area and PMP Area are summarized on Table 20 and are shown graphically on Figures 30 and 31 for the CMP Area and Figures 32 and 33 for the PMP Area. Tritium was detected in all groundwater and surface water samples submitted for analysis indicating the presence of some component of modern recharge (since circa 1952) at all sample locations. These results suggest that some groundwater recharge may occur along preferential flow pathways within the fractured bedrock. The concentrations of tritium in surface water and groundwater samples ranged from 3.2 to 10.1 TU. Tritium results for all samples, with the exception of the PM Air Shaft sample from 50-foot bgs (10.1 TU), were less than the USEPA Region 2 10-year precipitation average of 8.4 TU.

Because ^{14}C inferred groundwater ages were greater than 60 years for most samples, time of recharge based on tritium concentrations was not estimated. Mixing of older water (greater than approximately 60 years) that does not contain tritium with "modern" recharge water that does contain tritium will result in an erroneous estimate of time of recharge based on the tritium concentration alone. However, reviewing the ^{14}C and tritium data together indicates that most, if not all, groundwater samples contain a mixture of older water that is hundreds to thousands of years old and "modern" water that was recharged from precipitation since circa 1952. Groundwater samples with older inferred radiocarbon ages based on ^{14}C results contain a higher proportion of older groundwater than those with younger inferred radiocarbon ages. For example, the RW-5/5A and RW-3 series well clusters versus the RW-6/6A well cluster. As described previously, in the PM and CM Mine Areas, this mixing of "older" water with "modern" water likely occurred during filling of the underground mine workings after dewatering of the mines ceased circa 1960.

Specific observations for the CMP Area include:

- Lower tritium concentration in RW-8 (deeper bedrock) groundwater suggests limited hydraulic connectivity with the shallow mine pit groundwater.
- Highest tritium in three bedrock locations, the pit, and one surface water sample indicate greater proportion of water from "bomb pulse" (ca 1955 to 1965).
- Mixing of water probably accounts for intermediate concentrations of tritium in the shaft water. Similar ages in nearby wells reveal possible connection of wells with mine working.
- Limited influence of modern water in some deep bedrock wells.

Specific observations for the PMP Area include:

- Highest tritium in the PM Air Shaft, up-gradient surface water, and intermediate depth bedrock water at RW-5 may indicate greater influx of modern precipitation (i.e., greater proportion of water from "bomb pulse" -ca 1955 to 1965).
- Lowest tritium at wells RW-4 and RW-4A down-gradient of mine shows least influence of modern water.
- Tritium in surface water decreases from upstream of the pit to downstream of the pit. This may indicate increased discharge of older groundwater along stream channel.

6.4.3 Radon-222

Radon-222 (^{222}Rn) is a radioactive isotope with a half-life of 3.82 days. ^{222}Rn is derived from decay of radium-226 (^{226}Ra) within the uranium-238 (^{238}U) decay series. Radon is highly soluble and inert, and transport of radon occurs primarily via diffusion from the rock matrix where it is formed and via diffusion and advection in groundwater. Higher concentrations of ^{222}Rn in groundwater are typically associated with granitic rocks that contain elevated concentrations of ^{238}U, especially where the ^{238}U and ^{226}Ra content of the bedrock is concentrated along fracture walls where groundwater can come into contact with ^{222}Rn near the point of origin (Cecil and Green 2000). Concentrations of ^{222}Rn in groundwater may vary widely, even over relatively short distances within the same hydrologic environment (Cecil and Green 2000).

The presence of radon indicates actively circulating groundwater and can be used to identify groundwater discharges to surface water that is otherwise free of radon (Clark and Fritz 1997). Radon can also be used to evaluate rock permeabilities, fluid movements, and residence times. For the purposes of the Supplemental RI, the ^{222}Rn data were utilized to evaluate potential connection of surface water and groundwater and potential connection of water in the PMP Area and CMP Area and in the PM and CM shafts with surrounding groundwater.

Consistent with accepted protocol, samples for ^{222}Rn analysis were collected in three 40-milliliter (mL) glass vials with Teflon®-lined septa and were shipped at ambient temperature in coolers according to standard chain of custody procedures. Samples were analyzed for ^{222}Rn content at the ALS Environmental Laboratory located in Fort Collins, Colorado using Method SM7500-RNB.

Findings - CMP Area

Results of the ^{222}Rn analysis for the CMP Area are summarized on Table 20 and are shown graphically on Figures 34 and 35. Within the CM Shaft and the CMP well SC-02, ^{222}Rn activities in groundwater were below detection. These results suggest overall relatively stagnant conditions in the CMP Area underground workings and limited influx of bedrock groundwater that contains measureable activity of ^{222}Rn, as well of a lack of ^{238}U-containing materials within the fill in the CMP Area. Bedrock groundwater may be entering the CM Shaft, CMP, and CMP Area underground workings that has had limited contact with uranium mineral containing bedrock. However, the residence time of groundwater in the CM Shaft, CMP, and CMP Area underground workings likely is substantially greater than the half life of ^{222}Rn. Therefore, any ^{222}Rn that may be entering the CM Shaft, CMP, and CMP Area underground workings with bedrock groundwater rapidly decays to concentrations that are below detection. As indicated by the detection of ^{222}Rn activity at surface water monitoring location SW-MRB-01, bedrock groundwater is discharging to Mine Brook in the vicinity of the CMP Area.

Other specific observations for the CMP Area include:

- Non-detect ^{222}Rn activity in CM shaft may be indicative of limited contact with ^{238}U-containing minerals, and no hydraulic connection to other naturally occurring ^{222}Rn sources.

- ^{222}Rn activity is generally higher in shallow bedrock. There may be higher fracture density in shallow bedrock exposing more of the naturally occurring ^{238}U and ^{226}Ra to support observed ^{222}Rn activity.

In general, the ^{222}Rn analysis results have limited utility for evaluating connectivity in the CMP Area.

Findings - PMP Area

Results of the ^{222}Rn analysis for the PMP Area are summarized on Table 20 and are shown graphically on Figures 36 and 37. Within the PM Air Shaft, ^{222}Rn was detected in groundwater only at the 50 foot sample depth (67 picocurie(s) per liter [pCi/L]), suggesting an active connection between water in the PM Air Shaft and the surrounding bedrock within the upper portion of the shaft (i.e., water flows from bedrock into the shaft at shallower depth interval(s) that are less than 180 feet in depth within the PM Air Shaft).

Low or non-detect ^{222}Rn activity in PM air shaft indicates possible limited contact with naturally occurring ^{238}U-containing minerals or a stagnant water zone that allows decay of the ^{222}Rn. It also suggests that there is no hydraulic connection to the shallow bedrock where highest ^{222}Rn activity is observed.

In the PMP Area, ^{222}Rn was not detected in surface water samples, with the exception of a ^{222}Rn detection of 46 pCi/L in Park Brook sample SW-PAB-01 located immediately adjacent to the PMP Area. The detection of ^{222}Rn at SW-PAB-01 indicates that groundwater that contains ^{222}Rn (likely from overburden or shallow bedrock) is discharging to surface water in the vicinity of SW-PAB-01. Based on gaining conditions observed for Park Brook, groundwater is discharging to surface water at other locations along the channel based on known seeps and iron-staining to the streambed; however this groundwater discharge cannot be tracked using only ^{222}Rn, either because additional groundwater discharging to surface water does not contain ^{222}Rn or the ^{222}Rn is rapidly off-gassing from surface water.

6.4.4 Anthropogenic Gases

Chlorofluorocarbon (CFC) and sulfur hexafluoride (SF_6) are anthropogenic gases that have been released to the atmosphere since the 1930s and 1940s (CFCs) and since the 1960s (SF_6). Very small quantities of these gases dissolve naturally in water and, because of low analytical detection limits, detection of one or more of these gases is an indication of modern groundwater recharge

(Ekwurzel et al. 1994; Cook and Solomon 1995). SF_6 and three CFCs (trichlorofluoromethane [CFC-11], dichlorodifluoromethane [CFC-12], and trichlorotrifluorethane [CFC-113]) were evaluated as part of the Supplemental RI conducted in 2012.

CFC samples were collected according to the procedures provided by the United States Geological Survey (USGS) Reston Chlorofluorocarbon Laboratory. Bottles and caps were thoroughly rinsed with sample water prior to filling. Dedicated tubing was used for each sample location. Four CFC samples were collected per location into Boston round clear glass bottles (125 mL) with aluminum-lined caps and no headspace. Bottles were filled and capped underwater in a 4-L beaker after at least 2 to 3 L of water were allowed to flow through the bottle and out of the beaker. Caps were secured using black electrical tape, and samples were stored and shipped inverted to the University of Utah Dissolved and Noble Gas Lab located in Salt Lake City, Utah. Samples were analyzed for CFCs using Method GCE23, which includes purge-and-trap gas chromatography with an electron capture detector. The CFC data were corrected for salinity, recharge elevation, and recharge temperature using a standard calculation tool provided by the laboratory.

SF_6 samples were collected in two 1-L plastic safety-coated amber glass bottles with polyseal cone-lined caps. The pump tubing was placed at the bottom of the 1-L bottle and allowed to fill and overflow, such that approximately 3 L of the water to be sampled flowed through the bottle. The tubing was slowly removed from the bottle while the water was flowing, and the bottle was capped tightly without any headspace. Caps were secured to the bottle using tape. The bottles were placed in a cooler and shipped at ambient temperatures according to standard chain of custody procedures to the University of Utah Dissolved and Noble Gas Laboratory. Samples were analyzed for SF_6 using vacuum extraction gas chromatography on Shimadzu GC8a gas chromatograph with an electron capture detector. The SF_6 data were corrected for salinity, recharge elevation, recharge temperature, headspace losses, and excess air using a standard calculation tool provided by the laboratory.

The apparent recharge year for water samples was calculated by identifying the concentration of SF_6 and each CFC in air that would be in equilibrium with the water concentration and correlating that concentration to an equivalent atmospheric air concentration at the time of recharge. Concentrations of CFCs and SF_6 in the atmosphere since 1940 are shown on Figure 38, and the data are provided in University of Utah CFC and SF_6 data packages provided in Appendix G of this RIR.

CFC and SF_6 data may be influenced by a number of factors relating to both sampling and current and historical activities at the Site. Factors affecting CFC and SF_6 apparent ages include the following (Ekwurzel et al. 1994; Cook and Solomon 1995; Plummer and Busenberg 2000; Busenberg and Plummer 2000):

- Rapid or focused recharge, for instance in fractured rock where “excess” air can become trapped during recharge, can result in an apparent age that is much younger than expected.

- CFC and SF_6 mixing ratios in air in urban and industrial areas can exceed regional values and result in an apparent age that is younger than expected.

- Microbial anaerobic degradation of CFCs under sulfate-reducing and methanogenic conditions can result in apparent ages that are older than expected. Biodegradation is more prevalent for CFC-11 and CFC-113, while CFC-12 is relatively stable.

- Sorption, either to particulate and soil matter or to plastic used during sampling, may release or retain CFCs resulting in either older or younger than expected apparent ages. Generally, sorption is not a concern when dedicated plastic tubing is used during sampling.

- Natural (terrigenic) production of SF_6.

In addition, the atmospheric concentrations of CFC-11 and CFC-113 are not always unique. As shown on Figure 38, the atmospheric concentrations of CFC-11 began declining in 1994, and as of 2001 had declined to approximately the same value it was in 1989. Therefore, unique recharge dates cannot be generated based on CFC-11 concentrations for the period from 1989 to 2001. The same challenge exists for CFC-113 starting in 1991. However, comparison of estimated groundwater ages based on SF_6 and the different CFCs can be used to constrain the interpretation of possible ages.

Findings

The CFC and SF_6 analytical results are summarized on Table 20 and CFC results are shown graphically on Figures 39 and 40 for the CMP Area and on Figures 41 and 42 for the PMP Area. As shown, CFCs were detected in all surface water and groundwater samples collected at the Site indicating some component of “modern” recharge (since circa 1940) is present at all monitoring locations. Measured CFC concentrations ranged from 0.07 to 82.64 picomoles per kilogram (pmol/kg) for CFC-11, from 0.14 to 364.36 pmol/kg for CFC-12, and from 0.01 to 7.81 pmol/kg for CFC-113. As shown in Table 20, the highest concentrations of CFCs were measured in groundwater samples collected within and near the PMP and the CMP.

When converted to equivalent concentrations in atmosphere, concentrations of CFC-11 and CFC 12 in many surface water and groundwater samples exceeded maximum atmospheric concentrations by up to two orders of magnitude. These CFC results indicate that local CFC sources are present at the Site which may be associated with the various fill materials at the Site. Therefore the CFC analysis has limited utility for evaluating hydraulic connections at the Site.

As shown on Table 20, recharge dates were estimated for CFC concentrations that did not exceed atmospheric maxima although the accuracy of the recharge date estimates is complicated by the potential addition of CFCs from fill materials and dilution from mixing with older CFC-free water.

In the CMP Area, CFC-12 concentrations in most groundwater samples exceeded the maximum atmospheric concentration (Table 20). The highest CFC-12 concentration was detected in the groundwater sample collected at bedrock well OB-2 located in close proximity to the CMP with CFC-12 concentrations in groundwater generally decreasing with distance from well SC-02 located within the CMP. These results suggest a hydraulic connection between some groundwater monitoring locations with elevated concentrations of CFC-12. Concentrations of CFC-11 were elevated above atmospheric maximum in the vicinity of the CMP at wells OB-2, OB-3, SC-02, and RW-10A. Similar to the CFC-12 results, the CFC-11 results suggest a hydraulic connection between some groundwater monitoring locations with elevated concentrations of CFC-11. However, as previously stated, given that CFC are ubiquitous to the waste disposal areas, the CFC analysis has limited utility for evaluating larger-scale hydraulic connections at the Site.

CFC-12 concentrations in CM Shaft groundwater samples ranged from 19.2 to 27.4 pmol/kg; however, CFC-12 was detected in bedrock well OB-4 groundwater at a concentration of 1.26 pmol/kg, well below the atmospheric maximum. These data suggest that shallow bedrock OB-4 groundwater is not hydraulically connected, or is only minimally connected, with groundwater in the CM Shaft.

Recharge years based on the excess air adjusted SF_6 concentrations are shown in Table 20 and the analytical results are provided in Appendix G. As shown, SF_6 was detected in all surface water and groundwater samples that were analyzed, indicating the presence of some component of "modern" recharge (since circa 1952) at all monitoring locations. Note that sample bottles for SW-11, RW-3DD (175-180), RW-4 (393-403), and RW-4A (62-72) broke en route to the laboratory and the sample bottle for RW-10 (120-130) broke during temporary storage at the laboratory; therefore, analyses were not conducted for these samples.

As shown on Table 20, the reported concentrations of SF_6 ranged from 0.06 to 15.37 femtomoles per kilogram (fmol/kg). Some samples had reported concentrations that were higher than the calibration range for the analysis as denoted in Table 20 with SF_6 concentrations greater than 15 fmol/kg. The highest concentrations of SF_6 were measured in groundwater samples collected within and near the PMP and CMP Areas and the CM Shaft. Elevated SF_6 concentrations were also reported in groundwater samples collected at bedrock well RW-4A (113-123) and RW-4 (333-343) located downgradient of the PMP Area and the PM Air Shaft.

When measured, SF_6 concentrations were converted to equivalent partial pressures in atmosphere, many values exceeded maximum atmospheric concentrations, as denoted with a "C" in Table 20 in column “Apparent Recharge Year” (excess air correction 0 milliliters per gram [mL/g]). Potential causes of elevated SF_6 concentrations in groundwater and surface water samples include:

- Entrainment of “excess air” into groundwater during recharge
- Local source of SF_6 in fill material
- Regional source of SF_6 in the atmosphere
- Generation of SF_6 in crystalline bedrock

Excess air is air dissolved in groundwater in concentrations that are in excess of solubility for equilibrium with the atmosphere. Excess air occurs when air is trapped and dissolved under increased hydrostatic pressure in groundwater at the capillary fringe or in fractures as the water table rises. The air that is trapped is in relative proportions equal to that of the troposphere. The presence of excess air will result in an underestimate of actual recharge “age.” Sample SF_6 concentrations can be adjusted using an estimated excess air correction. Sampling for estimation of potential excess air was not conducted at the Site.

Therefore, SF_6 concentrations were adjusted assuming excess air values of 0.0, 0.02, and 0.3 mL/g (Alan Rigby, University of Utah, personal communication). The excess air values are indicative of no excess air (0.0 cubic centimeters per gram [cm^3/g]), excess air values typical for aquifers in unconsolidated sediments (0.02 cm^3/g), and more extreme values potentially applicable to fractured bedrock systems (0.3 cm^3/g).

Similar to CFCs, fill materials may include items that contain SF_6. SF_6 is mainly used as an electrical insulator in high-voltage switches and transformers and as an inert gas in high-temperature magnesium metal production. However, switches and transformers were not observed in fill material and concentrations of SF_6 were lower in groundwater samples collected at PMP and CMP sampling locations than in samples collected at nearby overburden and bedrock groundwater monitoring locations. Therefore, local SF_6 sources in fill material are unlikely.

Regional atmospheric concentrations of SF_6 may be elevated due to the proximity of the Site to large urban centers. Regional contributions of SF_6 are expected to be smaller than for CFCs because SF_6 is typically not present in common household products. However, excess SF_6 has been reported for air in the vicinity of New York City (Ho and Schlosser 2000). Atmospheric concentrations of SF_6 have not been measured in the vicinity of the Site; therefore, the potential magnitude of regional SF_6 sources is unknown.

Finally, natural production of SF_6 does occur and SF_6 from natural sources can result in groundwater concentrations significantly higher than that possible for modern air-water equilibrium. Significant concentrations of naturally occurring SF_6 have been measured in samples of volcanic, sedimentary, and igneous rock (especially granite) and in some hydrothermal fluids (Busenberg and Plummer 2000). Busenberg and Plummer (2000) measured high concentrations of SF_6 in hot springs from volcanic and igneous areas that were on the order of elevated concentrations of SF_6 detected in site groundwater samples. The presence of natural “terrigenic” SF_6 confounds the entire dating range for groundwater in mixtures that contain a fraction of old water. Due to the uncertainty in the magnitude of natural SF_6 contributions to Site groundwater, SF_6 data were not used to estimate time of groundwater recharge.

6.4.5 Stable Oxygen and Hydrogen Isotopes of Water

The stable isotopic composition of oxygen and hydrogen in water can be used to identify primary recharge source(s) for groundwater and surface water (e.g., snowmelt versus rainfall) and potential secondary effects due to evaporation or water-rock interactions. Stable oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$ or δD)[3] composition of water will shift, or fractionate, as a result of meteorological processes (including, but not limited to, temperature, evaporation, and condensation), allowing use of isotopes to trace the source of water. Differences in meteorological processes, as well as fractionation that occurs during evaporation or during water-rock interactions, may provide a characteristic fingerprint for origin of water.

Typically, the isotopic composition of surface water and groundwater reflects that of local precipitation. The variance in the $\delta^{18}O$ and δD values of precipitation at a particular location is described by a local meteoric water line (MWL), which is the best fit linear regression line through precipitation data (Figure 44). As the water from precipitation (rain or snow) interacts with rocks and minerals in the subsurface (typically on a geologic timescale), the isotopic signature shifts away from the MWL and takes on a signature specific to the groundwater of that region. Thus, deviations from MWL provide information about reactions and processes within an aquifer (Clark and Fritz 1997).

Consistent with accepted protocol for these specific parameters, samples for analysis of stable oxygen and hydrogen isotopic composition of water were collected into 30-mL high-density polyethylene bottles with no headspace. Samples were shipped at ambient temperature in coolers

[3] Stable oxygen and hydrogen isotopes of water are measured against known standards and are reported in δ (delta) notation in units of ‰ (per mil), as shown below for oxygen (Clark and Fritz 1997):

$$\delta^{18}O\ (‰) = ([(\delta^{18}O_x/\delta^{16}O_x) \div (\delta^{18}O_s/\delta^{16}O_s)]-1) \times 1000$$

where subscript x denotes sample and subscript s denotes standard. Negative δ values indicate that there is less of the rare isotope in the sample relative to the standard (i.e., the sample is “depleted” relative to the standard). Positive δ values indicate that there is more of the rare isotope in the sample relative to the standard (i.e., the sample is “enriched” relative to the standard).

according to standard chain of custody procedures. Samples were analyzed for stable oxygen and hydrogen isotopic composition at IT^2 on a Picarro cavity ring down spectroscopy analyzer.

The analytical results are summarized on Table 20 and provided in Appendix G. As shown, PMP and CMP Area surface water and groundwater samples had a relatively small range in $\delta^{18}O$ and δD isotopic composition with ($\delta^{18}O$ values ranging from -6.88‰ to -8.97‰ and δD values from -41.2‰ to -56.7‰ [Figures 23 and 24]). These stable oxygen and hydrogen isotopic composition values are consistent with measured values for precipitation samples collected in the region (-5.9‰ to -8.7‰ for $\delta^{18}O$ and -37.5‰ to -53.4‰ for δD) (USGS online database). Sample $\delta^{18}O$ and δD compositions were compared with the global meteoric water line and the local MWL derived from Kendall and Coplen (2001). Water sample $\delta^{18}O$ and δD isotopic compositions do not deviate significantly from the local MWL, indicating that water has not undergone significant change due to evaporation or water-rock interactions.

As shown in Table 20, for samples collected within the CMP Area, there is more overlap in the $\delta^{18}O$ and δD values for bedrock, CMP, and CM Shaft samples than observed for samples collected within the PMP Area. These results are consistent with CFC-12 data which showed a possible hydraulic connection among many of the groundwater bedrock well locations within the CMP Area. Groundwater at well locations RW-10(120-130) and RW-10(185-195) had the most negative $\delta^{18}O$ and δD values potentially indicating a less significant hydraulic connection with other groundwater well locations within the CMP Area.

As summarized in Table 20 and shown on Figure 45, for samples collected within the PMP Area, there is a grouping of bedrock samples with more negative $\delta^{18}O$ and δD values than other samples and a grouping of overburden groundwater and surface water samples that have more positive $\delta^{18}O$ and δD values. Shallow bedrock samples collected at wells RW-5A and RW-6A are similar in composition to PM Air Shaft samples and may indicate a mixture of water from deeper bedrock and shallower water sources, including shallow bedrock and the overburden.

Alternatively, these results may indicate a mixture of water recharged from snowmelt (more negative $\delta^{18}O$ and δD values) and rainfall (more positive $\delta^{18}O$ and δD values). The stable isotopic composition of surface water is most similar to overburden groundwater potentially suggesting that groundwater discharging to surface water is generally from overburden or shallow bedrock groundwater sources.

6.4.6 Geochemical Parameters

The geochemical composition of water can be used to evaluate similarities or differences in groundwater composition among sampling locations. Geochemical samples were collected using standard low-flow groundwater sampling collection methods. The samples were collected into a variety of vessels for the analytical parameters described below. Samples were shipped on ice according to standard chain of custody procedures. Samples were analyzed at Accutest Laboratories in Dayton, New Jersey, using the SW-846 methodology as described in the USEPA-approved QAPP (ARCADIS 2004b). The geochemical analytical suite included the following:

- Calcium, potassium, magnesium, and sodium via USEPA 6010B
- Total and dissolved iron and manganese via USEPA 6010B
- Sulfate and chloride via USEPA300/SW846 9056A
- Nitrate via USEPA 353.2
- Alkalinity via SM20 4500CO2D and SM20 2320B
- Fluoride via USEPA300/SW846 9056A
- Silica via USEPA 6010B
- Benzene via SW846 8260B
- TOC via SM20 5310B, 9060 M
- Total phosphorus via USEPA 365.3
- Methane and carbon dioxide via RSK-175

In addition, geochemical parameters measured in the field included groundwater pH, conductivity, DO, ORP measured as Eh, and TDS, which were measured after purging and prior to sample collection.

Major ion concentrations, including iron, calcium, sodium, potassium, magnesium, chloride, sulfate, carbonate, and bicarbonate concentrations were evaluated using Piper (Figures 47A and 47B) and Stiff diagrams (Figures 48A through 48E). Piper and Stiff diagrams are used to visually display different water types to aid in determining patterns in the geochemical data that can be evidence of potential similarities, or actual hydraulic connection or communication between different groundwater from different sources. Based on the major ion analytical results, the dominant water type for each monitoring location was determined and is summarized in Table 21.

The Piper Diagram for the CMP Area groundwater samples (Figure 47B) does not show obvious groupings in the major ion signatures, and there is no predominant water type evident. The samples collected from within the CM Shaft show some variability in major ion signature with depth, with the sample collected from 50 feet showing a distinctly different signature compared to other CM Shaft samples. Groundwater at deep bedrock well RW-2(452-462) located adjacent to the CM Shaft is a sodium-chloride type water with relatively high solute concentrations which may represent the quality of water in deep regional bedrock. Some of this saline sodium–chloride signal may be present in the CM Shaft groundwater samples collected at 100, 180, and 275 feet bgs potentially indicating upward migration of deeper bedrock groundwater through the CMP Area underground workings.

The Stiff Diagrams for CMP Area groundwater (Figures 48D), show a similar water composition among CM Shaft samples collected at depths of 50, 100, 160, and 275 feet bgs. Groundwater samples collected at shallow bedrock wells OB-2 and OB-3 are similar in composition to each other. Although well SC-02 located within the CMP plotted near bedrock wells OB-2 and OB-3 on the Piper diagram (Figure 47B), solute concentrations are substantially higher in well SC-02 groundwater compared with groundwater at bedrock wells OB-2 and OB-3 (Figure 48D). Bedrock groundwater at sampling locations in the vicinity of the CMP (including well clusters RW-8, RW-9, and RW-10) have a geochemical composition that is different from groundwater at well SC-02 with relatively higher sodium concentrations at the bedrock groundwater monitoring locations compared with SC-02. These results suggest contributions of solutes from dissolution of different mineral assemblages within bedrock in the CMP Area.

A Piper Diagram for the PMP Area, presented as Figure 47A presents the results of geochemical analysis of groundwater. This diagram shows that the majority of overburden, bedrock, surface water and PM Air Shaft monitoring locations, are dominated by calcium-bicarbonate water type.

The major ion signature within the PM Air Shaft shows little variability with depth, with monitoring locations generally clustered on the Piper diagram (Figures 47A). While the PM Air Shaft samples show some similarity to the surrounding bedrock and unconsolidated overburden units, water in the PM Air Shaft samples typically exhibit a higher proportion of sulfate and chloride than observed at other locations.

Generally bedrock and overburden groundwater monitoring locations are closely grouped, with little variability in terms of overall major ion signature. The exceptions are bedrock monitoring locations RW-3DS, RW-3DD, RW-5A, RW-5 and RW-6. Bedrock monitoring locations RW-3DS and

RW-3DD are sodium/potassium and sulfate dominant, and show a distinctly different major ion signature to other locations. While bedrock locations RW-5 and RW-5A are bicarbonate dominant, they do not show strong dominance within the major cations, and have distinctly different overall major ion signatures. The major ion signature at bedrock location RW-4 at 333 to 343 feet bgs, is slightly different to other bedrock locations and is grouped close to that observed in the PM Air Shaft.

Unconsolidated overburden monitoring wells OB-11R, OB-20B, and OB-27, bedrock monitoring well RW-6A, and PMP monitoring well SC-01, all of which also had detectable concentrations of benzene (Table 20) during this monitoring event plotted closely on the Piper Diagram (Figure 47A). These samples plotted separately from the PM Air Shaft samples suggesting different water sources for the PM Air Shaft compared with the OB-11R, OB-20B, OB-27, RW-6A, and SC-01 grouping. This may also indicate a separate source of benzene for the PM Air Shaft and the low concentrations of benzene detected in this grouping of shallower wells with detected concentrations of benzene in groundwater.

Surface water monitoring location SW-PAB-00 is dominated by sodium/potassium-bicarbonate water, and shows a distinctly different signature to other groundwater and surface water monitoring locations.

Stiff Diagrams for the PMP Area (Figures 48A through 48C) show similar water composition for the PM Air Shaft samples with overall low solute concentrations. However, as with the noted lack of benzene detections in samples collected in April 2012 from the PM Air Shaft at 180 and 230 feet bgs, previous sampling for groundwater geochemistry conducted in 2006 and 2007 has demonstrated calcium-bicarbonate type water with much higher solute concentrations. These results indicate that the low solute concentrations detected in the April 2012 PM Air Shaft samples are an outlier.

Two groupings of groundwater composition were noted for overburden monitoring locations. One group is OB-19, OB-20A, and OB-21 with relatively low solute concentrations. The second group is OB-11R, OB-20B, and OB-27 with relatively higher solute concentrations and a composition similar to that of SC-01 in the PMP. Shallow bedrock groundwater at RW-6A was also similar in composition to the second grouping of overburden and PMP groundwater, although solute concentrations were higher in the bedrock well. These results suggest a hydraulic connection (but not necessarily much movement as the hydraulic conductivity in bedrock, as shown by very low sustainable well purge rates, is poor) between water in the PMP and groundwater at downgradient monitoring wells OB-20B, RW-5/5A, RW-6A, OB-27, and OB-11R (Figure 48B).

There is greater variability in geochemical composition for bedrock monitoring locations with deeper groundwater samples (e.g., RW-3DS, RW-3DD, and RW-4 – 333-343) typically having different compositions or higher solute concentrations than shallow bedrock groundwater. While bedrock location RW-4 at 333 to 343 feet bgs shows some similarity in water type to the PM Air Shaft based on the Piper Diagram (Figure 47A), the concentrations of major ions at RW-4 at 333 to 343 feet bgs are higher than observed within the PM Air Shaft for the April 2012 sample but are similar in composition and concentration to the 2006 PM Air Shaft samples.

In the PMP Area, benzene was detected in overburden groundwater samples collected at OB-11R, OB-19, OB-20B, and OB-27 and in bedrock groundwater samples collected at RW-6 and RW-6A. Benzene was also detected in samples collected at SC-01. Monitoring wells OB-20B, RW-6 and RW-6A are located near to each other on the eastern edge of the PMP. Detected concentrations of benzene at these locations suggest a hydraulic connection between the bedrock and overburden at these locations. Benzene concentrations at CMP Area monitoring locations were typically below detection (0.22 µg/L), with the exception of monitoring location RW-2 (279-289) where benzene was detected at a concentration slightly above the detection limit (0.25J µg/L) and RW-8 (204-214 at a concentration of 0.58 µg/L), but below the GWQS of 1 µg/L in September 2014.

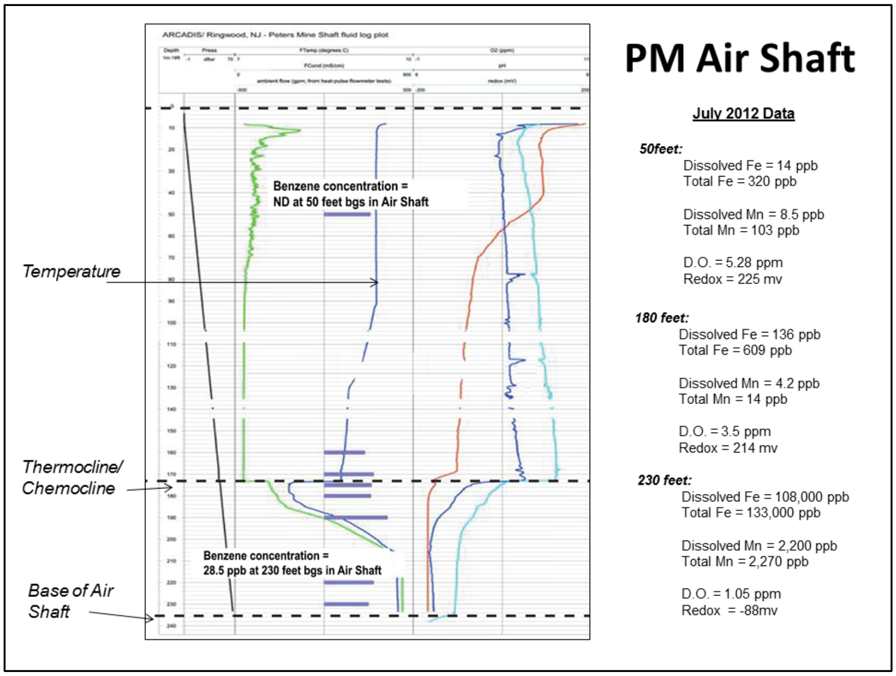
In the PMP Area, iron and manganese concentrations are typically highest in the unconsolidated overburden aquifer compared to the bedrock aquifer. The highest concentrations of dissolved iron and manages are observed in both aquifers at those locations where benzene is present above detection. Dissolved iron and manganese may be present in groundwater due to microbially mediated reducing conditions at these locations. This interpretation of iron and manganese reducing conditions is supported by depleted sulfate and nitrate concentrations, and elevated methane and carbon dioxide concentrations in groundwater at locations with elevated dissolved iron and manganese. These results indicate that moderate to strongly reducing conditions are present in some portions of site groundwater, particularly at locations where benzene is present.

While concentrations of sulfate and nitrate in the PM Air Shaft are below detection, concentrations of dissolved iron and dissolved manganese at these locations are also low, as are methane concentrations. There does not appear to be evidence of strongly reducing conditions at these locations. This contradicts previous results that have indicated very high concentrations of dissolved iron in PM Air Shaft samples with strongly reducing conditions indicated. Benzene concentrations are decreasing in groundwater with time at all locations in the PMP Area where benzene has historically been detected. The groundwater redox geochemistry suggests that benzene degradation may be slowed by the presence of moderately to strongly reducing conditions.

The review of existing chemical and geochemical data in the PM Air Shaft is consistent with the stratification and observed thermocline the water in the PM Air Shaft water, as discussed in Sections 5 and 7. As previously documented, geophysical logging identifies a break in slope along the temperature profile, or a thermocline, at a depth within the air shaft of approximately 175 feet bgs. This thermocline coincides with a chemical and geochemical stratification with pronounced variations in concentrations of:

- Benzene
- Dissolved and total iron
- Dissolved and total manganese
- Dissolved oxygen

The observed geochemical and chemical variations support the existence of a chemocline. Moreover, the geochemistry data show that groundwater conditions are predominantly aerobic (or oxidizing) above the thermocline/chemocline (50-180 feet bgs) and groundwater conditions are anaerobic (or reducing) at the base of the air shaft (230 feet bgs). Together, the thermocline and chemocline are consistent with expected and established flooded mine workings phenomena, where stratified conditions exist as a result of isolated mine areas that have no drainage or flow pathway at depth. One of several unique characteristics of thermocline/chemocline is that the stratification itself limits physical mixing between the water above and below the depth of stratification. Therefore, the existence of the thermocline/chemocline inside the air shaft effectively inhibits vertical migration and establishes a natural mechanism that contains the low levels of benzene to the area at the base of the air shaft.



6.4.7 Redox Geochemistry

Organic carbon compounds contained in TOC in groundwater can serve as sources of carbon and/or energy (substrate) for naturally occurring bacteria, and biodegradation of these constituents can occur by both aerobic and anaerobic microbial processes. Bacteria obtain energy for cell production and maintenance by facilitating oxidation-reduction reactions involving the transfer of electrons from electron donors (i.e., organic carbon) to available electron acceptors (including, but not limited to, DO, ferric iron, and manganese). In aerobic environments, DO serves as the electron acceptor and becomes reduced while the primary substrate (in this case benzene) is oxidized.

Under anaerobic conditions, other inorganic compounds (such as nitrate, ferric iron, manganese IV, sulfate, and carbon dioxide) act as electron acceptors and become reduced while the primary substrate is oxidized. Anaerobic oxidation processes consume these alternate electron acceptors in the following order of preference: nitrate (nitrate reduction), manganese (manganese IV reduction), ferric iron (ferric iron reduction), sulfate (sulfate reduction), and carbon dioxide (methanogenesis).

The primary bacteria involved in anaerobic oxidation are the denitrifying, iron-reducing, sulfate-reducing, and methanogenic bacteria, all of which are widely distributed in the natural environment. Denitrifying, iron, and sulfate bacteria use nitrate, oxidized iron and manganese, and sulfate as electron acceptors, and subsequently reduce them to nitrite or nitrogen gas, dissolved (ferrous) iron and manganese, and hydrogen sulfide, respectively. Methanogens use carbon dioxide as an electron acceptor, reducing it to methane. During anaerobic oxidation, the reduced electron acceptor (e.g., nitrite, sulfide, and methane) is often excreted from the cells, resulting in geochemical changes in the groundwater environment and detection of higher levels of these parameters in groundwater. Geochemical changes in groundwater and analysis to quantify the various electron acceptors and respiration byproducts in groundwater can be used to assess whether the aerobic and/or anaerobic bacteria are present and active under the existing geochemical conditions at the Site.

The redox geochemistry of groundwater was evaluated as part of the Supplemental RI and analytes included in the evaluation are summarized in Table 22. These redox geochemistry analytes include nitrate, sulfate, total dissolved iron and manganese, TOC, methane, and carbon dioxide. These data are used to evaluate groundwater redox conditions and to assess the potential role of redox geochemistry in the natural attenuation of benzene, lead, and arsenic in groundwater.

The groundwater geochemistry data do not exhibit obvious evidence to suggest a common water type between the CM Shaft, the CMP Area, and groundwater in the surrounding bedrock (Figures 47B and 48D). However, as indicated by other data discussed above, there are varying degrees of hydraulic connection and communication for groundwater within the CMP Area. These results do not mean that there is no hydraulic connection between these CMP features. Rather, differences in groundwater geochemistry likely reflect the interactions of groundwater with different mineral assemblages in the bedrock as groundwater migrates along its various groundwater flow paths and ultimately to surface water. As previously discussed and as shown in Table 20, many CMP bedrock groundwater samples had radiocarbon groundwater ages of hundreds to thousands of years indicating substantial time for groundwater to interact with bedrock minerals, as reflected by the groundwater geochemistry data.

In the CMP Area, elevated concentrations of dissolved iron and manganese have only been detected in groundwater samples collected at the CM Shaft, bedrock well OB-4 (periodically), and bedrock well OB-5 located in the vicinity of the Borough Landfill (Figures 49A and 49B). Groundwater redox parameters for these locations indicate moderately to strongly reducing conditions, indicating a redox control on dissolved iron and manganese concentrations at these monitoring locations. Unlike the PMP Area and OCDA, these metals are not elevated in groundwater in the immediate vicinity of, or downgradient of the CMP. Groundwater redox geochemistry at other monitoring locations in the CMP Area indicate moderately reducing to mildly reducing or aerobic conditions that are less conducive to dissolution of iron and manganese.

6.5 Stable Isotope Probing and Bio-Trap® Investigation

To supplement the extensive groundwater quality database generated over the many years of monitoring at the Site and verify whether or not microbially enhanced natural attenuation mechanisms have affected the residual benzene concentrations in groundwater within the PMP Area, a stable isotope probing (SIP) study using Bio-Trap® samplers was performed as part of the Supplemental RI conducted in 2012.

As defined in the November 2011 Interstate Technology & Regulatory Council Guidance document for the use of Environmental Molecular Diagnostics (EMD), EMD is a group of advanced and emerging techniques used to analyze biological characteristics of soils, sediments, groundwater, and surface water that have allowed the quantification of microbial organisms known to degrade specific chemicals and to actually measure key enzymes created in the biodegradation processes. These data not only confirm that the key microbial organisms are present, but also that they are active. These data are key to determining if natural attenuation processes are actively influencing the reported concentration of the constituent of concern.

SIP is one of the deoxyribonucleic acid- (DNA-) based EMD techniques that use isotopically enriched constituents as “tracers” or “probes” that can be incorporated into the microbial biomass to characterize constituent-specific biodegradation processes. Through this incorporation, SIP directly and unequivocally establishes whether or not biodegradation of a specific constituent is currently occurring in the environment.

SIP is implemented using Bio-Trap® samplers, which are passive sampling tools that are placed within a groundwater monitoring well to collect microbes over time for the purpose of better understanding biodegradation potential *in situ*. Bio-Trap® samplers incorporate a sampling matrix of Bio-Sep® beads that are 2 to 4 millimeter in diameter and are an engineered composite of Nomex® and powdered activated carbon. When a Bio-Trap® sampler is deployed in a monitoring well, the Bio-Sep® beads absorb constituents and nutrients present in the aquifer, essentially becoming an *in situ* microcosm with a very large surface area (~600 square meters per gram), which is readily colonized by microorganisms naturally occurring in the subsurface. Once recovered from a monitoring well (typically 30 to 60 days after deployment), DNA, ribonucleic acid (RNA), or phospholipid fatty acids (PLFA) can be extracted from the beads to evaluate the microbial community.

When used in a SIP study, Bio-Trap® samplers can be loaded with the targeted ^{13}C-labeled compound prior to deployment in a well. After retrieval, the SIP Bio-Trap® is analyzed for ^{13}C within biomass using PLFA, and for ^{13}C-DIC or ^{13}C-CO_2. As ^{13}C is present naturally at <1% in the environment, the presence of ^{13}C within either biomass or dissolved inorganic carbon (DIC) or CO_2 demonstrates biodegradation of the ^{13}C-labeled compound has occurred. It should be noted that the method by which ^{13}C is analyzed for in biomass (PLFA) only includes bacterial populations, and does not include methanogenic biomass as these organisms belong to the domain *Archaea*, therefore do not contain phospholipid fatty acids within their cell membrane structure. If active, ^{13}C uptake into the biomass associated with methanogens and the ^{13}C associated with their end product (methane) will not be accounted for by this analysis.

As summarized in Table 23, these SIP techniques were incorporated into the Supplemental RI work scope. The Bio-Trap® samplers were deployed within the PM Air Shaft at the 180 and 230 feet bgs depth intervals and well SC-01 located within the PM pit, as well as in key PMP Area groundwater monitoring wells, including overburden wells OB-11R, OB-20A, OB-20B, OB-27 and bedrock wells RW-6 and RW-6A. The Bio-Traps® were deployed in the monitoring wells in June 2012 and within the PM Air Shaft in August 2012.

Following a 33-day deployment period, the Bio-Trap® samplers were removed and shipped according to standard chain of custody procedures to Microbial Insights located in Rockford, Tennessee. In accordance with the Supplemental RI Work Plan, the biomass that grew on the Bio-Sep® beads was analyzed for the following:

1. The presence and abundance of known petroleum degrading bacteria using Quantitative Polymerase Chain Reaction analysis, both present and function, reported as messenger ribonucleic acid (mRNA) gene expression.

2. The percent mass loss of ^{13}C-labeled benzene from each Bio-Trap® using benzene analysis.

3. Mineralization of the ^{13}C-labeled benzene into DIC.

4. Incorporation of the ^{13}C-labeled benzene into the cell structure of the indigenous microbial community through PLFA analysis.

^{13}C was incorporated into biomass at all locations included in the SIP Bio-Trap® study providing conclusive data that microbial populations capable of degrading benzene exist in PMP Area groundwater, including within the PM Air Shaft, the PMP, and at overburden and bedrock monitoring wells downgradient from the PMP. These results provide confirmation that benzene is actively being microbially degraded in PMP Area groundwater.

The groundwater monitoring locations selected for this study are located near the PMP and are screened at various depths within the overburden, bedrock, and backfilled areas. These monitoring locations currently have or historically have had detected concentrations of benzene in groundwater. During the April 2012 groundwater sampling event, concentrations of benzene in samples collected at the wells ranged from less than the laboratory reporting limit of 2.2 µg/L to 5.5 µg/L, consistent with the range of benzene concentrations (<0.22 to 6.5 µg/L) detected historically. Concentrations of benzene in groundwater in the PM Air Shaft were <0.24 and 28.5 µg/L in June 2012 for depths of

180 and 230 feet bgs, respectively, prior to deployment on August 14, 2012. Concentrations of benzene in the PM Air Shaft water have historically ranged from <0.22 to 26.4 µg/L at a depth of 180 feet bgs and from <0.22 to 33.2 µg/L at a depth of 230 feet bgs. Benzene has not been detected at concentrations above the laboratory reporting limits of 0.22 and 0.24 µg/L in PM Air Shaft groundwater at a depth of 50 feet bgs.

As shown on Table 17, concentrations of benzene are decreasing at most locations where benzene has historically been detected with the exception of RW-6A with respect to the 2013 and 2014 report results. Concentrations of nitrate, dissolved iron, dissolved manganese, sulfate and methane indicate that groundwater redox conditions at the Bio-Trap® sampling locations are generally moderately to strongly reducing. The presence of reducing conditions coupled with the decreasing benzene concentration trends suggests that biodegradation of benzene is occurring under anaerobic conditions at these locations. The detailed results of the SIP analyses are provided in the Microbial Insights laboratory reports provided in Appendix K.

The total biomass of microorganisms collected from the Bio-Trap® samplers ranged from approximately 3.0×10^4 to 1.5×10^6 cells/bead. The ^{13}C-enriched biomass ranged from 1.3×10^2 to 4.6×10^4 cells/bead and the average PLFA δ^{13}C values for each location ranged from 10 to 5184‰. These data indicate that a population of viable microorganisms in groundwater populated the Bio-Trap® samplers at all locations evaluated. Data are not available for methanogenic organisms, although the presence of methane at most sampling locations indicates these organisms are likely also present and active at these locations.

The concentrations of ^{13}C-labeled benzene decreased over the 33-day deployment period for all locations with the exception of the PM Air Shaft samples. At most locations, ^{13}C-labeled benzene loss ranged from approximately 25 to 32 percent, while benzene loss at OB-20A was 89 percent. ^{13}C derived from degradation of ^{13}C-labeled benzene was incorporated into microbial biomass at all monitoring locations, with the highest level of ^{13}C incorporation observed for well OB-20A. Incorporation of ^{13}C into the PLFA of microorganisms is a conclusive indicator of biodegradation. In addition, all locations demonstrated incorporation of ^{13}C into dissolved inorganic carbon indicating complete mineralization of the ^{13}C-labeled benzene via respiration. It should be noted that all locations contained significant levels (>1 mg/L) of methane, with the exception of the PM Air Shaft where methane was not analyzed for during the most recent sampling event. As discussed above, the presence of ^{13}C within methanogenic biomass and associated end product methane was not captured within this analysis, however these organisms are likely present and active at these locations.

Several types of microorganisms were detected on the Bio-Trap® samplers. The dominant microbial population (56 to 84 percent) was Proteobacteria (Monoenoics), which include many aerobic and anaerobic bacteria. The majority of bacteria that utilize hydrocarbons fall within the Proteobacteria structural group. The parameter used to indicate the physiological status of

Proteobacteria demonstrated that at most locations the microbial population was not exhibiting signs of response to environmental stress, indicating a viable microbial population.

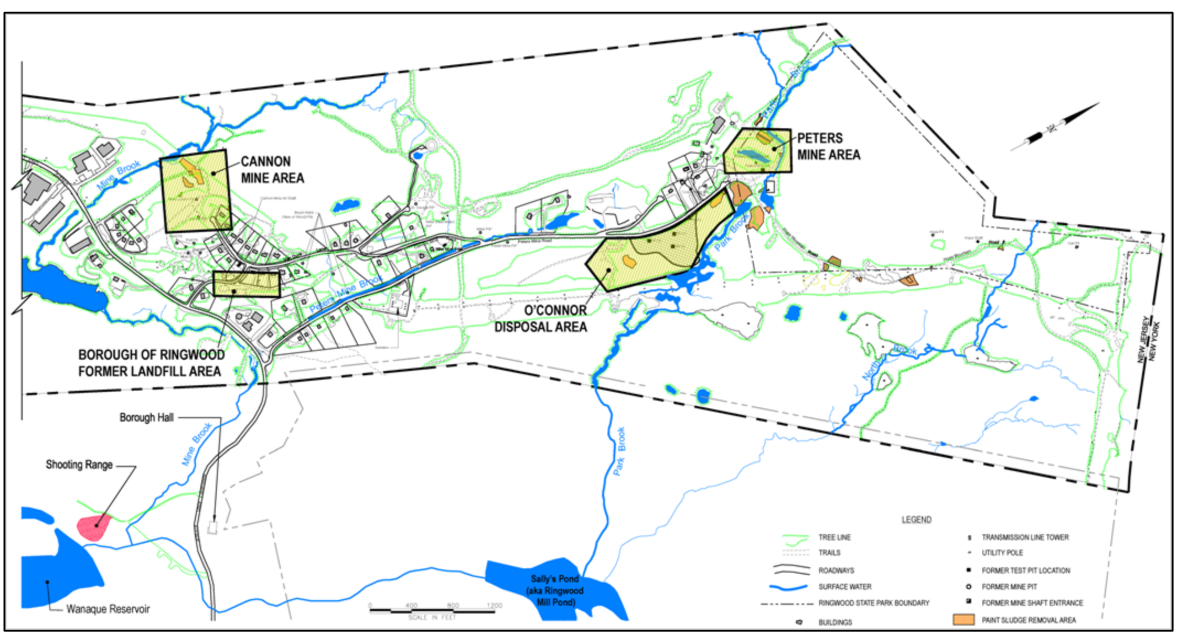
The genetic molecule that is present in some aerobic benzene-degrading microorganisms, phenol hydroxylase mRNA, was not detected in Site samples, indicating that while aerobic biodegradation of benzene may be occurring, it may not be a dominant biodegradation mechanism. This result is consistent with the generally moderately to strongly reducing conditions observed for groundwater at locations evaluated with Bio-Trap® samplers, which suggests that anaerobic biodegradation of benzene is a viable mechanism at these locations.

Biotrap™ data for the PM Air Shaft reveal biological uptake of Carbon-13 at both 180 feet bgs and 230 feet bgs, indicating that microbial degradation is occurring above and below the established thermocline/chemocline. The thermocline separates the deeper zone, where reducing conditions and slower anaerobic biodegradation is occurring, from the shallow zone, where oxidizing conditions occur resulting in faster aerobic degradation. The observed concentrations of benzene fit with the thermocline and, above the stratification, the data support the conclusion that the natural system is containing and controlling the benzene-impacted water.

7. Conceptual Site Model

The numerous investigation activities conducted at the Site since 1984 provide an extensive dataset for characterizing the nature and extent of Site-related constituents in groundwater and surface water. Moreover, the RI activities have been carried out to define the nature and extent of Site-related constituents in other media and identify and characterize key features (e.g., fractures in bedrock, transmissivity/connectivity, groundwater flow pathways) and mechanisms affecting groundwater quality at the Site (e.g., groundwater geochemistry, microbiology, natural attenuation). All these data taken together comprise a CSM for how constituents are transported in groundwater and surface water in the ACs and the overall Site. This section presents a CSM for each AC then compiles them to formulate a cohesive and comprehensive CSM depicting the entire Site setting and land surface features, including surface waters, ground surface topography, geology, and groundwater and surface water hydrology. For reference in support of the following analysis, groundwater and surface water analytical data are presented in Tables 13 and 14 and on Figures 16 through 18.

As described in Section 2, there is a long history of mining and disposal operations at the Site that have contributed to environmental impacts in the three ACs (see Site map, below, for locations of the land ACs). The large dataset assembled over the last 30 years covers a wide range of constituents, but the three primary COCs--benzene, lead, and arsenic--have been detected with the most frequency in groundwater samples, and to a much lesser extent, in surface water samples collected at the Site at concentrations that occasionally exceed relevant water quality standards. However, the detections of these constituents are limited in extent, the constituents are localized to



the immediate land AC at which they are detected, and there is no migration beyond the individual land ACs. As a result, there are no Site-wide plumes of any COCs in groundwater.

Key findings based on the RI data are as follows:

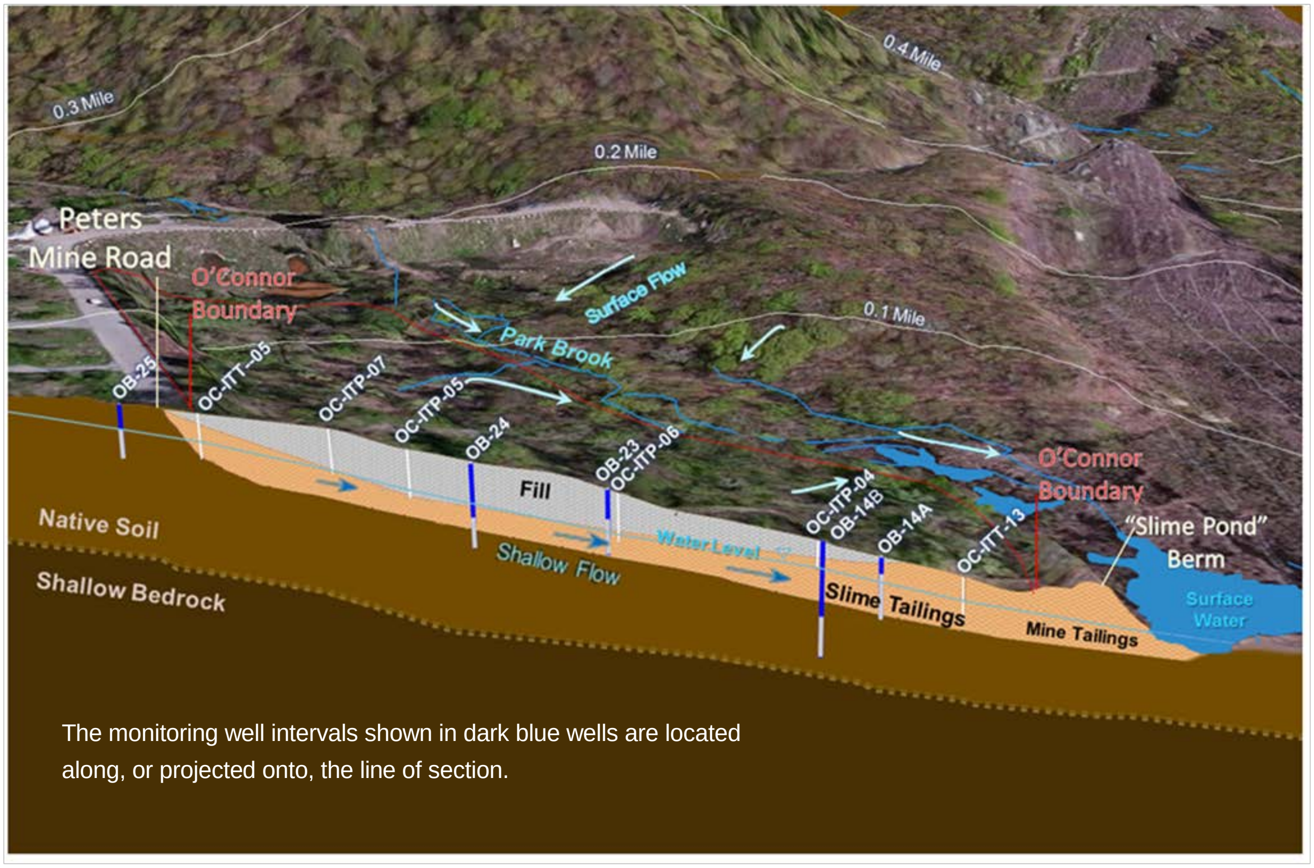
- Benzene in groundwater and surface water is localized to the PMP Area.
- Total, and to a lesser extent, dissolved arsenic in groundwater is sporadically detected in groundwater in the PMP Area and the OCDA.
- Total lead is sporadically detected in groundwater in the PMP Area, OCDA, and CMP Area.
- A mine pool is present in the PM Air Shaft.
- A forensic evaluation of sediment in the PM Air Shaft indicates that the sediment is not related to a paint waste origin.

In addition, there have been no downgradient or downstream detections of any Site constituents--including benzene, lead, and arsenic--in groundwater or surface water beyond the property boundaries during the nearly 30 years of groundwater and surface water monitoring. Therefore, there is no off-site impact, to surface water quality, including no Site-related exposure to the Wanaque Reservoir.

7.1 O'Connor Disposal Area

The OCDA is a former aboveground mine process waste disposal area and there are no mines or underground workings associated with the OCDA; therefore, the placement of fill materials was essentially surface deposition on top of the mine waste materials. Consequently, investigation of the OCDA focused on characterization of the fill material, underlying mine waste materials, and native soil. A graphic representation of the CSM for the OCDA is presented in Figure 50, below.

Figure 50. OCDA Conceptual Site Model



Based on test trenches, test pits, and soil borings completed within the OCDA, the native soil underlying the fill material within the OCDA is glacial till that is a mixture of sand, gravel, and silt. Soil within the upper 5 to 6 feet of the native soil profile is classified as Ridgebury loam by the United States Department of Agriculture. Where undisturbed, the native soil deposits are at least 40 feet thick and are underlain by the crystalline, metamorphic gneiss bedrock.

Shallow groundwater flows through the native overburden soil upgradient of the OCDA then through OCDA fill materials and mine process waste prior to discharging to Park Brook and wetlands on the eastern, downgradient OCDA boundary (Figure 15).

Groundwater elevation data generated during the RI confirm groundwater discharge into Park Brook. As expected, the depth to groundwater fluctuates seasonally and is typically deeper during drier summer months, with some wells being dry, or nearly dry, during drought conditions. As a result, groundwater discharge volumes to Park Brook vary seasonally.

Groundwater within the overburden aquifer in the vicinity of the OCDA has been characterized through installation and monitoring of nine overburden monitoring wells (Figure 13A). Groundwater occurs at depths typically ranging from a few feet to 15 feet bgs. Bedrock groundwater quality was not investigated under the OCDA because the groundwater quality documented by deeper overburden and downgradient overburden monitoring wells (OB-14B, OB-16, OB-17, and OB-18) confirmed no or limited detections of constituents at concentrations above their respective GWQS (Table 13).

As described in Section 5, VOCs and SVOCs have not been detected in groundwater at concentrations above the GWQS, and no VOCs, SVOCs, or metals have been detected in surface water above the relevant SWQS. Some metals detected in the fill and native soil are sporadically detected in the groundwater, but typically at concentrations below their respective GWQS. Both total and dissolved arsenic have been detected above the GWQS, but transport of arsenic in groundwater is limited to the immediate vicinity of the OCDA. At most OCDA groundwater monitoring locations, concentrations of arsenic have been decreasing with time, indicating that natural attenuation processes are influencing arsenic concentrations at the Site.

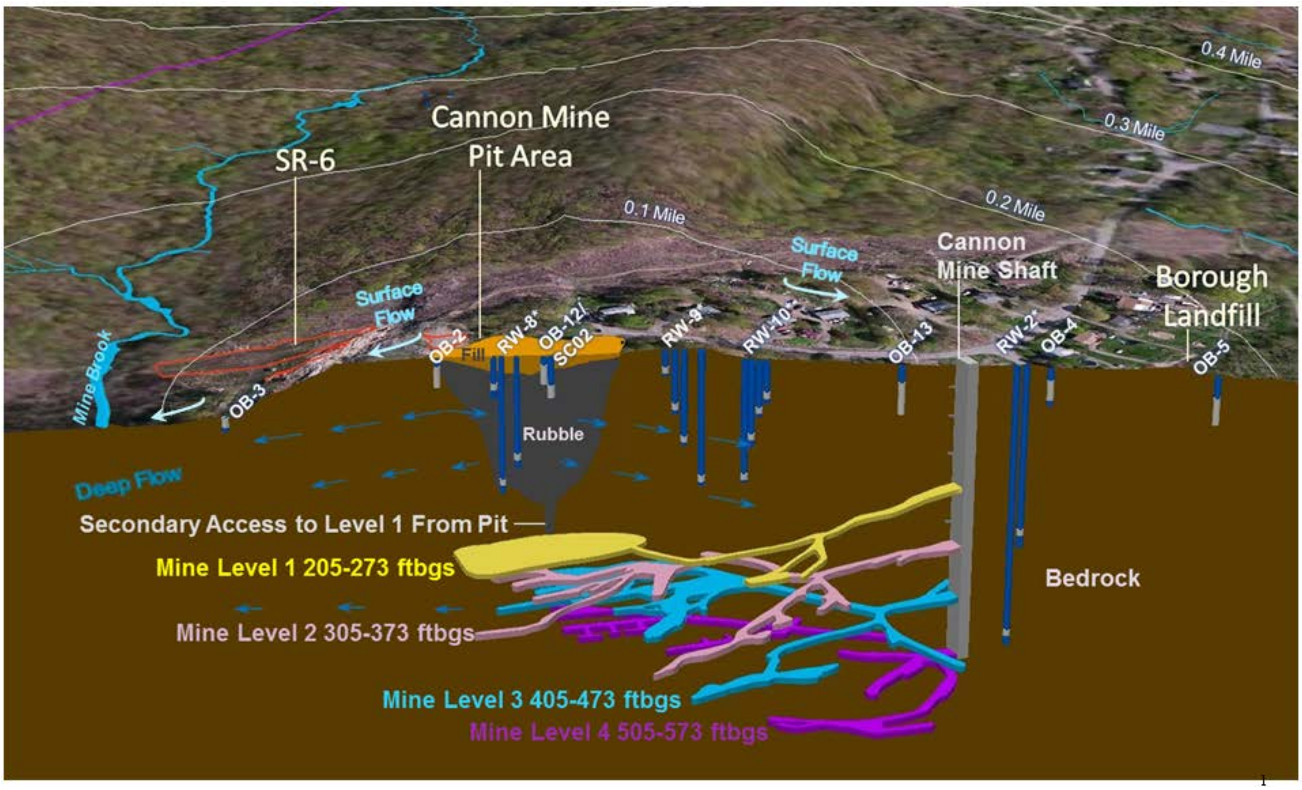
Groundwater geochemical conditions at downgradient monitoring locations (OB-17, OB-18, and OB-28; Table 22) are more oxidized than at locations within the OCDA, and these more oxidized conditions limit further migration of arsenic in groundwater. Dissolved arsenic will tend to precipitate and particulate arsenic will tend to sorb to the aquifer matrix under more oxidized conditions, thus limiting transport of arsenic in OCDA groundwater. Both total and dissolved lead have been detected above the GWQS at the OCDA. Total lead has consistently been detected above the GWQS at overburden well OB-25 located upgradient of the OCDA adjacent to an area where cars have been historically junked and dismantled so the presence of lead is not believed to be related to the OCDA. Total lead has been detected sporadically at concentrations above the GWQS in other wells at the OCDA; however, no COCs, including arsenic and lead, are migrating beyond the OCDA.

Collectively, these results confirm that COCs in OCDA groundwater are not migrating beyond the OCDA, and surface water is not impacted.

7.2 Cannon Mine Pit Area

The CMP Area is a former mine pit located on a bedrock ridge that slopes steeply to the west and gently to the south and east. The CMP Area has underground mine workings and a very large mine pit that was closed by blasting the sides in 1965. The pit was not filled to ground surface after it was closed, and was subsequently used as a landfill where industrial and municipal-type wastes were deposited above the blast rock. Because this land AC is located on a bedrock ridge, the overburden is thin to non-existent and, where present, is draped over shallow bedrock encountered at depths of less than 10 feet bgs. The CSM of the CMP Area is represented in a block diagram cross-section in Figure 51, below.

Figure 51. CMP Conceptual Site Model



Groundwater occurs in the shallow and deeper bedrock and within the mine pit but the overburden, where it occurs, is too thin to sustain a water-bearing zone and is unsaturated. Groundwater in the shallow bedrock is monitored at depth intervals on the order of tens of feet bgs, and the deeper bedrock groundwater is monitored on the order of several hundreds of feet bgs to a maximum depth of 462 feet bgs at well RW-2, as shown in Table 1. As previously discussed in Section 4.6.2, based on the decrease in occurrence of fractures with depth in the bedrock and the low yield of monitoring wells during purging and sampling as repeatedly documented during the multiple groundwater sampling events conducted at the Site during the RI, the data indicate that the horizontal and vertical hydraulic conductivity of the bedrock in the shallow and deeper monitoring zones is limited due to poor vertical permeability and low transmissivity.

As shown on Figure 51, because the overburden in the CMP Area is thin to non-existent, heavy precipitation tends to run off as stormwater to surface water rather than infiltrate into bedrock, although recharge directly into the pit will occur. Groundwater flows radially away from the crown of the bedrock ridge (higher elevations to lower elevations) toward Mine Brook in a manner similar to stormwater runoff. The crown of the ridge represents an approximate location of a groundwater divide and the CMP breeches the crown of the ridge and thereby alters the flow of groundwater on the divide (Figures 12A and 13A). The existence of the CMP and other CMP Area pits and underground workings affects groundwater flow by creating alternate directions for both shallow and deeper groundwater. Depending upon recharge and seasonal fluctuations in water levels, groundwater flow directions may locally reverse, resulting in groundwater flow towards the CMP. Ultimately, groundwater flows from the CMP Area to the west and south/southwest towards Mine Brook, creating base-flow in the perennial stream that ultimately discharges to Ringwood Creek, and eventually to the Wanaque Reservoir.

VOC detections in groundwater at the CMP Area are limited. There were historical detections of TCE above the GWQS in shallow bedrock at well OB-3, which is located downgradient and down slope of the west side of the CMP, but TCE has not been detected at this location in the last three years of monitoring. There were recent detections of benzene at (2.2 µg/L in 2013 and at 0.58 µg/L in 2014 which is below the 1 µg/L GWQS) at bedrock well RW-8, but no previous detections at this well. Overall, the results of RI monitoring confirm there are no organic constituents at levels of concern in CMP Area groundwater.

Arsenic, lead, and other metals, including aluminum, iron, and manganese, are limited in their occurrence within groundwater in the CMP Area. Detections of these metals in CMP Area groundwater are sporadic showing no consistent pattern spatially or temporally, and are likely associated with native bedrock in this historical mining area. These results demonstrate that the fill within the CMP represents a limited and diffuse source of constituents that has not resulted in generating a definable groundwater plume.

Arsenic and lead are limited in their occurrence in surface water and have never been detected above the relevant SWQS in downstream samples leading to Ringwood Creek and Wanaque Reservoir. Each metal has been detected about the relevant SWQS at one location: for arsenic, in one sample collected below the CMP Area where the stream abuts SR-6 (Figure 18A), and for lead in one sample collected in 2012 at the same location (Figure 17A). No other detections above the SWQS have been recorded in other sampling events or at other locations, including the eight downstream sample locations from the Margaret King Boulevard culvert to just before the stream confluence with Ringwood Creek.

Taken together, the results of the RI confirm that the fill within the CMP and the CM Shaft is not a significant source of constituent concentrations in groundwater or surface water the COCs are not migrating beyond the CMP Area in either surface water or groundwater, and there are no adverse impacts to the Wanaque Reservoir or to the Borough of Ringwood drinking water wells located farther downgradient and in a separate watershed.

7.3 Peters Mine Pit

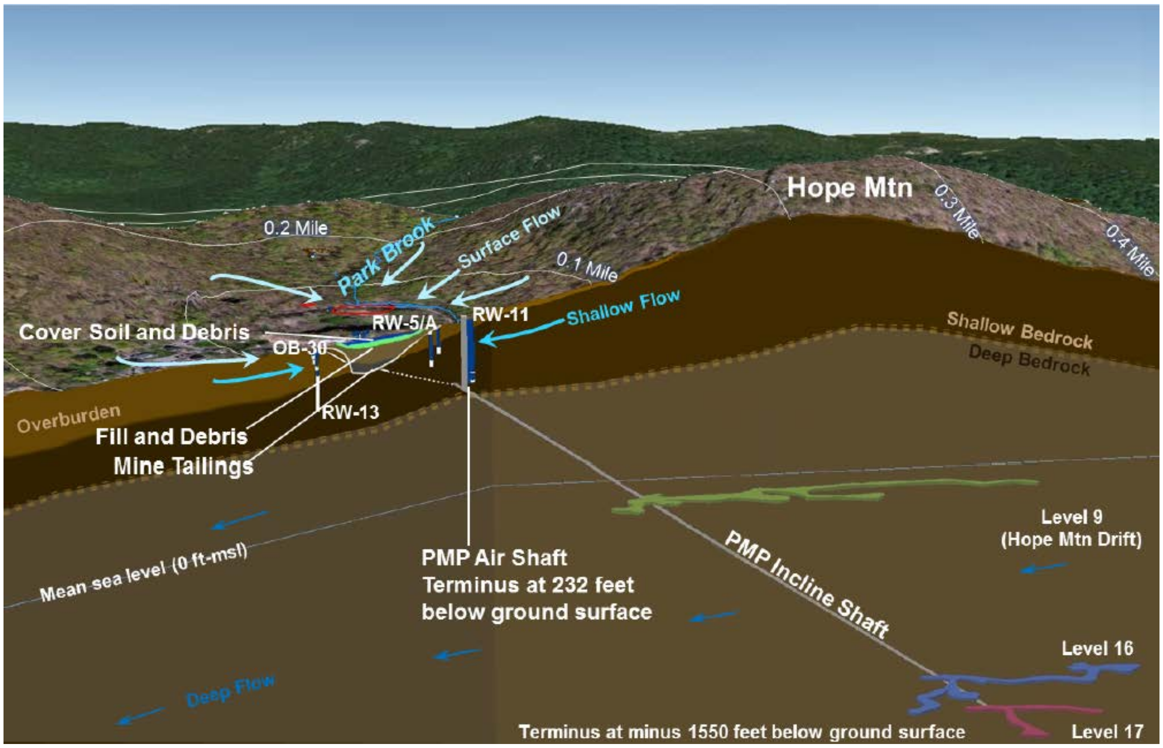
The PMP Area is located at 500 feet above sea level at the head of a valley and the terrain consists of a relatively flat area where the mine pit is located. The PMP Area is surrounded by mountains with peaks that are up to 900 feet above sea level to the north, west, and east. Unconsolidated soil and sediment deposits are primarily confined to the stream valley where Park Brook is located. Bedrock in the area of the mine pit and the valley head and other topographically low areas is generally covered by overburden, which consists of unconsolidated and reworked glacial deposits and weathered bedrock. In the vicinity of the PMP, the overburden is overlain by excavated rock, mine tailings, refuse, and fill soil.

Groundwater in the PMP Area occurs in the overburden, shallow bedrock, and deeper bedrock. The overburden is up to 60 feet thick in the PMP Area and the depth to groundwater in the overburden ranges from 12 to 17 feet bgs. Shallow bedrock groundwater is present on the order of tens to 200 feet bgs (shallow bedrock), and deep bedrock groundwater is present on the order of 200 to perhaps 500 to 600 feet bgs (potential limit of yield).

The transition from overburden groundwater to the shallow bedrock aquifer occurs through weathered bedrock. Results of the RI indicate that there is connectivity between the two aquifers, although it is limited under natural conditions by poor vertical permeability. In the PMP Area, the natural connectivity between overburden groundwater and shallow and deep bedrock groundwater has been locally altered by the presence and extent of the PM underground mine workings and does not represent a regional condition.

The abandoned underground mine workings represent a significant capacity for storage of groundwater, estimated to be 231,000,000 gallons (Getz 1965). Based on historical mine dewatering rates of approximately 53 gpm and low yields of groundwater from bedrock monitoring wells during purging and sampling, the underground mine workings do not appear to contribute to overall local hydraulic transmissivity within the massive crystalline bedrock. Moreover, this large volume of groundwater storage and lack of yield from PMP Area monitoring wells indicates that fractures in the bedrock have limited transmissivity and/or connectivity and the permeability of the bedrock is, therefore, limited. The CSM for the PMP Area is shown on a block diagram cross-section on Figure 52, below.

Figure 52. PMP Area Conceptual Site Model



The results of the RI, including the geochemical and environmental tracer study (Section 6.4), coupled with elevation data generated during the pressure transducer study (Section 6.3), show that in the PMP Area, groundwater in bedrock has an upward vertical potentiometric gradient, which indicates possible hydraulic communication between shallow and deep bedrock and also with groundwater in the overlying overburden. Recharge caused by precipitation into the bedrock in the surrounding mountains cannot be accommodated solely by the poor horizontal hydraulic transmissivity of the bedrock. Therefore, the limited groundwater movement in deeper bedrock may occur through high-angle fractures to the shallow bedrock or overburden aquifer where horizontal transmissivity is greater.

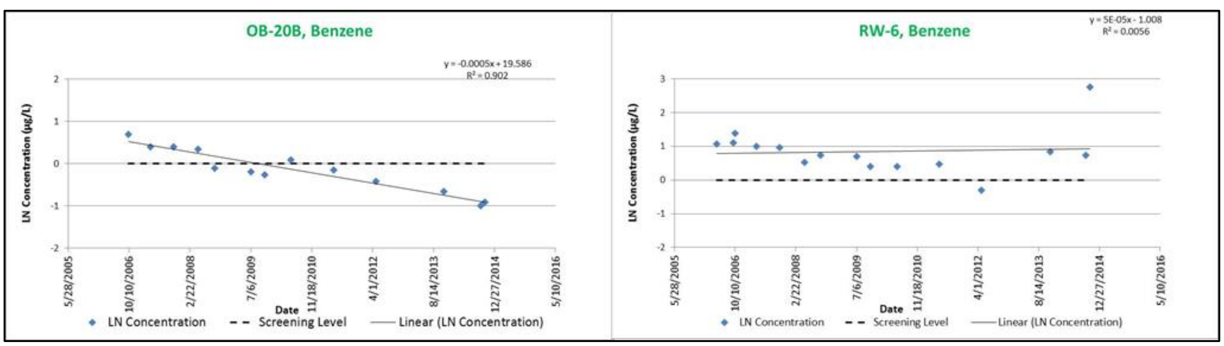
Shallow bedrock groundwater is mixing with the overburden groundwater. The transducer and stream staff gauging data, along with the results of the RI indicate that overburden groundwater mixed with the bedrock groundwater is discharging to Park Brook and through seeps in the vicinity of SR-3 (Figure 3). Excess water from storms that enters the PMP overland also discharges through overburden to surface water. As shown on Figure 3, surface water within Park Brook ultimately discharges into Sally's Pond (also known as Furnace Dam Pond), which ultimately discharges to Ringwood Creek approximately 1 mile upstream of its confluence with Wanaque Reservoir. The reservoir is located approximately 1.5 miles downstream of the PMP Area.

Benzene, arsenic, and lead have been detected above their respective GWQS at the PMP Area. Lead and, to a lesser extent arsenic, have been detected sporadically within and downgradient from the PMP. However, it is important to note that transport of arsenic and lead in groundwater and surface water to locations downgradient of the PMP Area is limited, and neither lead nor arsenic have been identified consistently in surface water or in groundwater downgradient beyond the immediate vicinity of the PMP. In the presence of aerobic conditions, the two metals most likely exist as insoluble oxide compounds.

Arsenic may be present in a soluble form in the reducing conditions found in groundwater in the PMP Area, but the reducing zone does not extend far from the PMP area, and oxidizing conditions exist along the length of the streams. This is supported by the data that show dissolved-phase arsenic and lead are rarely detected and, when detected, rarely exceed their respective GWQS.

Benzene in groundwater at the PMP Area is detected in the air shaft, overburden monitoring wells, and shallow bedrock wells nearest the PMP (Figure 16A), but has not been detected in groundwater beyond the PMP Area. This is demonstrated by groundwater samples collected from downgradient overburden monitoring wells OB-30A, OB-30B, and OB-30C; bedrock monitoring wells RW-3, RW-3D, RW-13S, and RW-13D; surface water samples collected at SW-PAB-01 and SW-PAB-01A (Tables 13 and 14), and sediment pore water samples collected from Park Brook (Table 16).

The trend analysis of benzene concentrations in both overburden and bedrock groundwater at the PMP Area demonstrate statistically significant decreasing to generally decreasing trends at most groundwater monitoring locations where benzene has historically been detected (Appendix J), as shown in the examples below.



The 2013 data for overburden and bedrock wells in the PMP area show that the benzene concentration at OB-20B continues to decrease with 2013 and 2014 sample results for benzene showing a detection of 0.55J µg/L and 0.37J µg/L, respectively. However, the benzene concentration in RW-6A increased from 2.0 µg/L in April 2012 to 15 µg/L in November 2013 and to 6.8 µg/L in October 2014. The benzene concentration in RW-6 increased slightly from an estimated value of 0.74 µg/L to 2.3 µg/L in November 2013 and 2.1 µg/L in September 2014. This increase of benzene observed at RW-6/6A well pair does not appear to correlate to a change in water levels or aqueous geochemistry. Additional groundwater monitoring at the PMP Area will be needed to assess whether this increase indicates a change or is just a temporary result.

Benzene concentrations remain essentially steady at OB-11R, whereas a continuing decreasing trend is apparent at OB-27 (6.5 µg/L in 2011, 5.5 µg/L in 2012, and 3.5 µg/L in 2013). Benzene remains non-detected in OB-20A, OB-21 and the RW-5/5A well pair.

As described in the discussion on the Bio-Trap® study (Section 6.5), benzene degradation is occurring in overburden and shallow bedrock groundwater at the PMP Area. Benzene degradation is enhanced where redox conditions are more favorable (e.g., less reducing to aerobic conditions in overburden groundwater at monitoring well OB-20A) and occurring at a slower rate where conditions are less favorable (more strongly reducing), as in the 220- to 230-foot depth interval in the air shaft.

Since initiation of Site-wide groundwater monitoring in 2005, the maximum concentration of benzene detected in groundwater was 33.2 µg/L in 2011 at a depth of 230 feet bgs in the PM Air Shaft (Table 13). Although benzene degradation rates in the air shaft are slower than in the overburden, the concentration of benzene detected in the deepest parts of the air shaft are still being reduced before reaching the shallow bedrock or overburden. This is confirmed by the data: the maximum concentrations of benzene detected in 2011 in overburden is 6.5 µg/L at OB-27 (Table 13) with a present (November 2013 data) benzene concentration of 3.5 µg/L at OB-27. Concentration declines continue before benzene reaches surface water in the AC. The maximum concentration detected in surface water was 1.2 milligrams per liter (mg/L) at monitoring location SR-3 Seep 1 in 2010 (Table 14).

Limited detections of benzene in surface water indicate discharge of benzene from groundwater to SR-3 seeps and surface water in Park Brook. However, benzene is not detected downstream of the groundwater discharge point, indicating that degradation and/or volatilization of benzene is occurring in the aerobic stream water. Therefore, the data confirm the mobility of benzene in PMP Area surface water is limited to several hundred feet.

Dissolved benzene in groundwater at the PMP Area exhibits higher concentrations in groundwater in the PM Air Shaft. Since initiation of groundwater monitoring conducted as part of the Site-related Groundwater RI in 2005, the highest benzene concentration reported in groundwater in the PMP Area was 33.2 µg/L at the 230-foot bgs depth interval at the base of the PM Air Shaft. The maximum benzene concentration reported in groundwater within any PMP Area overburden or bedrock well, including well SC-01, located within the PM pit, was 6.5 µg/L at overburden well OB-27.

The flow study documents an upward gradient in the PM Air Shaft, but benzene is at lower concentrations or absent in the intermediate and shallower depths of the air shaft. Benzene concentrations dissipate vertically until benzene becomes non-detected at the 50-foot sampling interval. This corresponds with increasing oxygen levels in the groundwater moving upwards in the shaft as can be observed in the fluid log plots (see Figure 53 below). Together, these data reveal the presence of a thermal and geochemical stratification of the water in the air shaft at approximately 170-180 feet bgs. Referred to as a thermocline and a chemocline, these are common phenomena in flooded mine workings (Wolkersdorfer 2008) , where stratified conditions exist as a result of isolated mine areas that have no drainage or flow pathway at depth. The presence of a thermocline creates conditions that limit the physical mixing between the water above and below the depth of stratification, thereby providing a mechanism that inhibits migration and actively contains the benzene at the base of the air shaft. Given that there is negligible lateral communication between the deeper shaft/mine workings and the surrounding bedrock aquifer, the low levels of benzene are contained and remain in an isolated layer of water within the air shaft.

The thermocline coincides with a chemical and geochemical stratification, with pronounced variations in concentrations of:

- Benzene
- Dissolved and total iron
- Dissolved and total manganese
- Dissolved oxygen

The geochemistry data show that groundwater conditions are predominantly aerobic (or oxidizing) above the thermocline/chemocline (50-180 feet bgs) and groundwater conditions are predominantly anaerobic (or reducing) at the base of the air shaft (230 feet bgs). The Biotrap® data reveal biological uptake of Carbon-13 at both 180 feet bgs and 230 feet bgs, indicating that microbial degradation is occurring above and below the thermocline/chemocline. Further C^{14} dating described in Section 6.4 indicates a mix of modern and old water in the air shaft. The older age of groundwater in bedrock wells and the absence of a modern age groundwater influence, confirms that there is little to no communication of water between the air shaft and the surrounding deep bedrock aquifer. In contrast, the modern signatures of water in the overburden and PM pit are consistent with influx and recharge of modern age rain water.

In summary, given the documented bioactivity above and below the thermocline/chemocline, and the diminished or lack of benzene above the stratification, the natural system is containing and degrading the benzene.

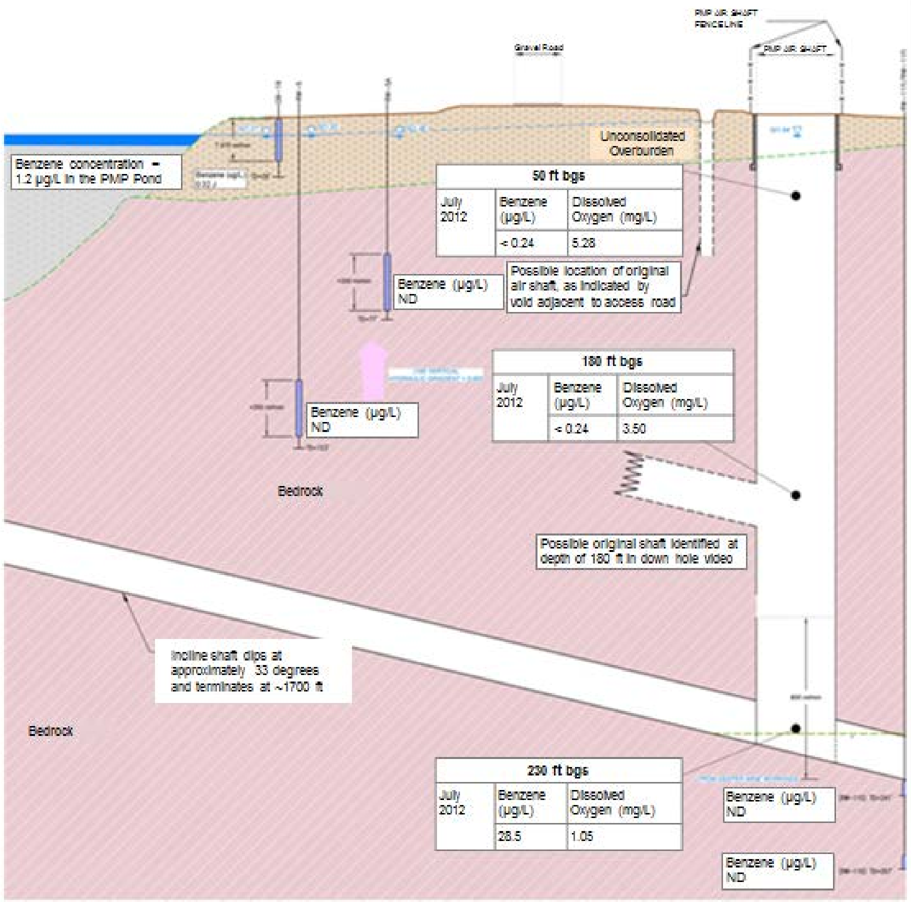
As discussed in Section 5.3.4, a forensic evaluation was conducted on the sediment sample collected at the base of the air shaft. The evaluation included a direct comparison of metals concentration and distribution, a cluster analysis of metals, a direct comparison of PAHs, and a comparison/evaluation of VOCs (including the potential effects of degradation). Based on this analysis, the chemical compositions in the paint waste and the sediment sample are found to be distinctly different from each other for metals, PAHs, and VOCs. In addition, degradation cannot account for the observed differences in the distribution of the metals, PAHs and VOCs. A mixing model analysis concluded that the sediment is more similar to manufactured gas plant sources (i.e., creosote, which is commonly found in mine timbers) and combustion sources (like urban dust/combustion from cars, gasoline-fired engines, or even fires rather than paint waste). In summary, the forensics analysis provides multiple line of evidence that conclude the sediment and paint waste are not related.

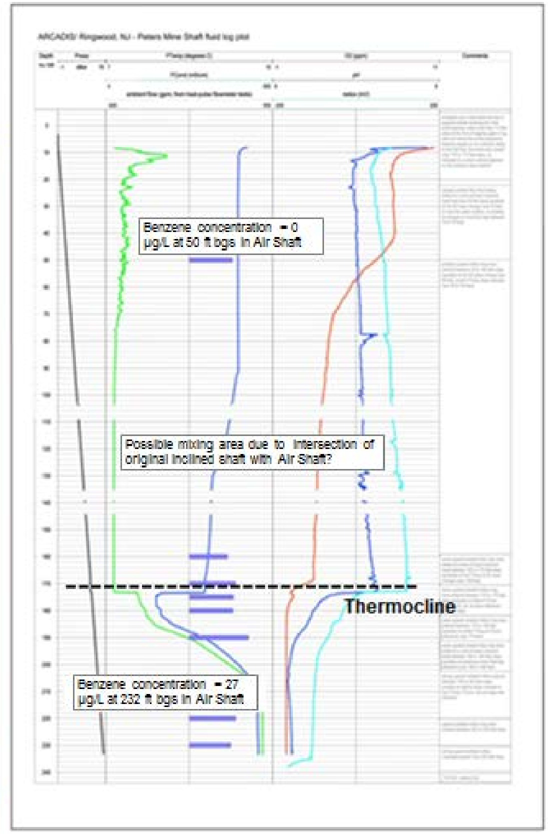
These conclusions that the sediment at the base of the PM Air Shaft are not related to paint waste are supported by the events leading to and thru the mine closure process as documented by the NJ Mine Safety Bureau (Getz 1965). Based on these documents, the following sequence of events occurred:

- 1960 - Mine pumps were removed
- 1967 - Mines fully flooded
- 1967 & 1971 - paint waste/waste disposal at the Site

Based on the timeline presented above, the paint waste disposal occurred after the mines were fully flooded. Given the sequence of events outlined in the timeline, the mine working were flooded by the time any paint waste disposal occurred. Moreover, there is no viable mechanism that would drive or deliver a benzene source to the base of the air shaft, across the observed stratification.

Figure 53. PMP Air Shaft Cross Section





7.4 Overall Site-Wide Conceptual Site Model

The overall Site-wide conceptual model synthesizes information generated during the investigations at the Site to present a summary picture of Site geology, hydrogeology, constituent distribution, and migration pathways through groundwater and surface water transport, and potential impacts to receptors. The purpose of this CSM-- shown graphically on Figure 54 -- is to provide a written and illustrative representation of Site conditions and the processes affecting the transport and migration of constituents through groundwater and in surface water.

The Site was an active iron mine that operated for more than 200 years. In addition to the mine workings, there was an iron mill at the Site to process the ore. This mill and other mine operations generated waste materials, including blast rock, unprocessed ore, and mine tailings. This waste material was disposed at the Site near the pits and in areas along Peters Mine Road. The Site also became a disposal location for solid waste (industrial- and municipal-type) and paint waste. Disposal of these wastes occurred at three landfill locations – the PMP Area, the OCDA, and the CMP Area. In addition, 16 other paint waste disposal sites have been identified. Cleanup is complete at fifteen of these areas, and work is underway at the final location.

The constituents associated with waste disposal at the Site include VOCs, SVOCs, PCBs, and metals, but the primary COCs at the Site are benzene, arsenic, and lead. All three of these constituents are found in paint waste, and arsenic is also found in mine tailings and ore. The distribution of these constituents in soil is mostly restricted to the landfill locations. In groundwater, the COCs are primarily found in the PMP Area and the OCDA and benzene is limited to the PMP Area. Constituent impacts to surface water are also localized to the landfill locations.

Groundwater at the Site is present in overburden deposits (glacial deposits, primarily till, and alluvial stream deposits consisting of reworked glacial till) ranging in thickness from 0 to 50 feet, where thickness is sufficient to support groundwater and within fractured bedrock underlying the overburden material. The overburden and bedrock form two separate aquifers that are in hydraulic communication. The depth to water ranges from 1 foot to 62 feet bgs. Groundwater is shallower in the valley than on bedrock slopes. Groundwater flow directions in both overburden and bedrock are locally influenced by topography, but generally flow down valley to the south and southeast. Purging of monitoring wells during sampling indicate that groundwater yield in the bedrock is poor and moderate to poor in the overburden. During historical mining activities, pumping of the PM underground workings at a rate of approximately 53 gpm was sufficient to dewater the workings to a depth of 1,700 feet bgs. This low flow rate indicates relatively limited capacity of the bedrock to transmit groundwater.

Groundwater level measurements, geochemical data, and isotope data indicate that bedrock groundwater has an upward vertical component, especially in the locations of underground mine workings. This vertical upward hydraulic gradient results in possible hydraulic communication between the deeper bedrock groundwater and the groundwater in the overburden and shallow bedrock. This upward migration occurs because the recharge of precipitation into the bedrock in the surrounding mountains cannot be accommodated solely by the horizontal hydraulic transmissivity of the bedrock. Therefore, water flows through high-angle bedrock fractures to the shallow bedrock or overburden aquifer, where horizontal transmissivity is greater.

Results from numerous investigations conducted at the Site indicate concentrations of COCs have been and continue to be affected by several mechanisms of natural attenuation. These attenuation mechanisms reduced concentrations and limit the migration of constituents in groundwater and surface water at the Site. Benzene concentrations are decreasing in groundwater primarily due to biodegradation, and transport of benzene from the landfill/source areas appears to be limited to a distance of several hundred feet. Where groundwater containing benzene is discharged to surface water, benzene is not detected within several hundred feet of the discharge zone, most likely due to volatilization or degradation of benzene in the oxygen-rich surface water. Transport of arsenic and lead in groundwater and surface water to locations downgradient of the landfill areas is limited. In the presence of aerobic conditions, the two metals most likely exist as insoluble oxide compounds. Arsenic may be present in a soluble form in the reducing conditions found in groundwater at the landfills, but the reducing zone does not extend far from the landfills, and oxidizing conditions exist along the length of the streams. This is supported by the RI data – dissolved-phase arsenic and lead are rarely detected and, when detected, rarely exceed their respective GWQS. The distribution of benzene, arsenic and lead and the ACs is shown on three site-wide cross-sections (Figures 19, 20, and 21).

When considering potential human exposure to COCs, there are no complete groundwater or surface water transport pathways. This finding is based on the collective recognition of the following facts:

- The land ACs at the Site range from approximately 0.5 mile (CMP Area) to almost 2 miles (PMP Area) upstream of the Wanaque Reservoir or other potable water supplies.
- The COCs in groundwater and surface water have limited mobility.
- In 30 years of groundwater and surface water monitoring, no concentrations of any COCs have been detected above relevant GWQS or SWQS downgradient of the Site.

While there is potential direct contact exposure to constituents in surface water at the landfill locations, concentrations of COCs in surface water rapidly attenuate a short distance from these landfills to levels that are below detection. No constituents – including benzene – have been detected in surface water downgradient of the Site, confirming the finding that this transport pathway is incomplete. Because benzene in groundwater is typically detected at concentrations below its vapor intrusion screening level for groundwater (15 µg/L for residential settings is the most conservation NJDEP vapor intrusion screening level for benzene in groundwater, and the maximum benzene concentration in the PMP Area overburden is 5.5 µg/L), and there are no structures in the PMP Area, the vapor intrusion pathway is also incomplete.

In summary, the complicated geology and hydrology of the Site are well understood, the occurrence and flow patterns of groundwater and surface water have been studied and confirmed, and the occurrence of COCs in groundwater and surface water has been documented as part of numerous studies completed over the past 30 years. Taken collectively, this body of data and information demonstrate that COCs are not migrating beyond the Site, drinking water supplies are not affected, and there are no complete transport pathways.

8. Summary and Conclusions

The Site has a long history of environmental investigation and cleanup beginning with the first investigation in the mid-1980s through the most recent investigation work completed in 2014. With the additional removal and disposal of approximately 50,000 tons of surficial paint waste, soil, and other waste materials between 2004 and 2014, source control is complete and only localized, residual conditions remain, which have been fully characterized and shown to be limited in extent to the immediate vicinity of the individual land ACs and in SR-16. The investigation activities completed between 2005 and 2014 were used to characterize the residual conditions and supplement historical data to develop a Site-wide CSM that provides the framework for describing the nature, extent, fate, and transport of key Site constituents, including benzene, lead, and arsenic, as described in the conclusions presented below.

- Extensive investigatory work conducted since 2005 is consistent with, and supports, the conclusions drawn based on the groundwater investigations conducted during the 1980s and 1990s.

- The comprehensive monitoring well network and surface water sampling locations, coupled with the geologic, hydrogeologic, geochemical and environmental data accumulated over the last 30 years of RI activities at the Site have enabled the **effective characterization of the nature and extent of Site-related constituents in groundwater** and a complete understanding of Site-wide groundwater flow pathways and.

- ***Groundwater sampling shows concentrations of the constituents are low and limited in extent.*** Benzene is localized to the PMP Area; arsenic is mostly detected in the PMP Area and OCDA, and lead is sporadically detected in the PMP Area, OCDA, and CMP Area.

- ***Constituents are not detected in surface water beyond the Site boundaries.*** Benzene is localized in the SR-3 seeps, and the Cannon/Diamond Seep; and arsenic and lead are periodically reported in the four streams at the Site, including upstream of the land ACs, but not at the downstream confluence with the Ringwood Creek.

- Concentration trend analysis indicates ***benzene concentrations in groundwater in the PMP Area are generally decreasing, likely due to ongoing natural attenuation, including microbial degradation which has been shown to occur under existing groundwater conditions at the Site***. The 2013 and 2014 groundwater results are generally consistent with the extensive historical groundwater analytical database for the Site (data outliers from PMP Area wells SC-01 and RW-6A withstanding), but some temporal variability is to be expected and the data indicate no other outlier data in adjacent or downgradient locations. In the PMP Area where the groundwater flow pathway has been documented using natural environmental tracers, groundwater discharges to Park Brook but benzene is not detected in Park Brook surface water and the discharge pathway is therefore incomplete.

- ***Arsenic and lead are detected sporadically at in groundwater with many of the historical concentrations reported in groundwater reflective in whole or in part to elevated groundwater sample turbidity but, where arsenic and/or lead occur in groundwater at levels above the GWQS,*** ,they likely exist as insoluble oxide compounds and concentrations readily decrease due to natural attenuation processes, including the presence of oxidized groundwater conditions beyond the reducing zone in the immediate vicinity of the PMP and OCDA land ACs. ***There is minimal bedrock flow in deep bedrock, but there is upward movement of groundwater from the bedrock along the preferential flow pathway created by the man-made underground mine workings*** *in the PMP and CMP Areas as well as flow in shallow bedrock that discharges to the four onsite streams that flow to the Ringwood Creek and eventually to the Wanaque Reservoir. RI data collected over the past 30 years confirm that, although groundwater discharges to surface waters at the Site,* ***the constituents associated with the Site are not transported in groundwater or to surface water beyond the Site boundaries and there are no off-site impacts to groundwater or surface water, including the Wanaque Reservoir*****.**

- Similarly, there are **no adverse impacts to Ringwood's municipal water supply wells located further downgradient and in a separate watershed from the Site.**

As stated previously, the results of more than 30 years of monitoring and the comprehensive Site-related Groundwater RI conducted at the Site support the conclusion that the Site groundwater and surface water occurrence, movement, and quality has been fully characterized, including the nature and extent, and fate and transport of constituents in groundwater and surface water, and an accurate Site-wide CSM has been developed.

With the RI complete and groundwater and surface water monitoring ongoing, it is therefore appropriate to begin the FS phase of the CERCLA process which can be conducted very expeditiously using the vast amount of scientific data generated during the RI regarding natural attenuation mechanisms influencing constituent concentrations in groundwater and surface water at the Site.

9. References

ARCADIS G&M. 2001. Final Summary Report for Post-Environmental Monitoring Activities, Ringwood Mines/Landfill Site, Ringwood, New Jersey. December 21.

ARCADIS. 2004a. Post-Environmental Monitoring Program Sampling Work Plan, Ringwood Mines/Landfill Site, Ringwood, New Jersey. July 26.

ARCADIS. 2004b. Quality Assurance Project Plan. Ringwood Mines/Landfill Site, Ringwood, New Jersey. May.

ARCADIS. 2005a. Plan for the Investigation of the Ringwood Mines/Landfill Site, Module 2: Work Plan for the Stream Sediment/ Surface Water Sampling Activities. July.

ARCADIS. 2005b. Plan for the Investigation of the Ringwood Mines/Landfill Site, Module 3: Investigation of the Peters Mine Pit Area. December.

ARCADIS. 2006a. Groundwater Sampling Work Plan. Ringwood Mines/Landfill Site, Ringwood, New Jersey.

ARCADIS. 2006b. Stream Sediment/Surface Water Sampling Report. Ringwood Mines/Landfill Site, Ringwood, New Jersey. May.

ARCADIS. 2007a. Groundwater Sampling Technical Memorandum – DRAFT. Ringwood Mines/Landfill Site, Ringwood New Jersey. March 13.

ARCADIS. 2007b. Letter to USEPA (Joe Gowers), Peters Mine Air Shaft Sampling. May 30,

ARCADIS. 2008a. Technical Memorandum – Site-Wide Groundwater Sampling. Ringwood Mines/Landfill Site, Ringwood, New Jersey. February 14.

ARCADIS. 2008b. Draft Technical Memorandum – Site-Wide Groundwater Sampling April/May 2008 Sampling Event. Ringwood Mines/Landfill Site, Ringwood, New Jersey. October 29.

ARCADIS. 2009a. Draft Technical Memorandum – Site-Wide Groundwater Sampling September 2008 Sampling Event. Ringwood Mines/Landfill Site, Ringwood, New Jersey. January 14.

ARCADIS. 2009b. Draft Technical Memorandum – Site-Wide Groundwater Sampling July 2009 Sampling Event. Ringwood Mines/Landfill Site, Ringwood, New Jersey. September 25.

ARCADIS. 2009c. Quality Assurance Project Plan. Ringwood Mines/Landfill Site, Ringwood, New Jersey. June.

ARCADIS. 2010a. Draft Technical Memorandum – Site-Wide Groundwater Sampling October 2009 Sampling Event. Ringwood Mines/Landfill Site, Ringwood, New Jersey. February 19.

ARCADIS. 2010b. Technical Memorandum – Site-Wide Groundwater Sampling. May/June 2010 Sampling Event. September 28.

ARCADIS. 2010c. Letter to USEPA (Joe Gowers), Cannon Mine Shaft Video Results. June 17.

ARCADIS. 2011a. Sediment Sampling Work Plan. Peters Mine Pit Pond. Ringwood Mines/Landfill Site, Ringwood, New Jersey. April 25.

ARCADIS. 2011b. Screening Level Ecological Risk Assessment Report – Peters Mine Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. June 2010. Revised March 2011.

ARCADIS. 2011c. Peters Mine Air Shaft Sediment Sampling, Ringwood Mines/Landfill Site, Ringwood, New Jersey. September 30.

ARCADIS. 2012a. Proposed Supplemental Site-Related Groundwater Remedial Investigation Work Plan. Ringwood Mines/Landfill Site, Ringwood, New Jersey. March 14.

ARCADIS. 2012b. Revised Baseline Human Health Risk Assessment for the Peters Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. March 24.

ARCADIS 2012c. Remedial Investigation Report for the Peters Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. July.

ARCADIS. 2012d. Revised Screening-Level Ecological Risk Assessment for the Peters Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. January.

ARCADIS. 2012e. Revised Screening-Level Ecological Risk Assessment for the Cannon Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. March.

ARCADIS. 2012f. Revised Screening-Level Ecological Risk Assessment for the O'Connor Disposal Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. June.

ARCADIS 2012g. Baseline Ecological Risk Assessment for the Peters Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. May 29.

ARCADIS. 2013a. Baseline Ecological Risk Assessment for the Cannon Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. May 10.

ARCADIS. 2013b. Remedial Investigation Report for the Cannon Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. June 7.

ARCADIS. 2013c. Remedial Investigation Report for O'Connor Disposal Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. June 10.

ARCADIS. 2013d. Baseline Ecological Risk Assessment for O'Connor Disposal Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. July 23.

ARCADIS. 2013e. Baseline Human Health Risk Assessment for the Cannon Mine Pit Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. September 11.

ARCADIS. 2013f. Baseline Human Health Risk Assessment for the O'Connor Disposal Area. Ringwood Mines/Landfill Site, Ringwood, New Jersey. September 19.

ARCADIS. 2013g. Supplemental Reconnaissance Survey Work Plan. Ringwood Mines/Landfill Site, Ringwood, New Jersey. August 25

ARCADIS. 2014. Surface Water and Sediment Pore Water Investigation Work Plan. April 21.

Brimer. Christopher. Old Mine Yields Water – Lots of It. Passaic County Edition. October 7.

Behum, P.T. and E.D. Christensen. 2006. Remediation of Acid Mine Drainage in the Sugar Creek Watershed, Missouri: Technology and Costs for Use in TMDL Assessment. March.

Busenberg, E. and L. N. Plummer. 2000. Dating young groundwater with sulfur hexafluoride: Natural and anthropogenic sources of sulfur hexafluoride. *Water Resources Res*., 36:, 3011-3030.

Caine, J.S., R.H. Johnson, and E.C. Wild. 2011. USGS Open-File Report 2011-1092. October.

Cecil, L.D. and J.R. Green. 2000. Radon-222. *In:* Environmental Tracers in Subsurface Hydrology, Cook, P. and A.L. Herczeg (Eds.), Kluwer Academic Publishers, Boston.

Clark, I. and P. Fritz. 1997. Environmental Isotopes in Hydrogeology. Boca Raton, Lewis Publishers.

Cook, P.G. and D.K. Solomon. 1995. Transport of atmospheric trace gases to the water table: Implications for groundwater dating with chlorofluorocarbons and krypton 85. *Water Resource. Res*. 31: 263-277.

Divine, C.E. and J. Humphrey. 2005. Groundwater dating with H-He, GW-391. *In* The Encyclopedia of Water. Jay H. Lehr, Ed. John Wiley and Sons.

Eastern Coalition for Abandoned Mine Reclamation. 2011. Mine Water Resources of the Anthracite Coal Fields of Eastern Pennsylvania. September.

Edmunds, A., and S. Miranda. 2010. Water Sustainability and Availability for Power Generation: Assessing Water Sustainability Options. September.

Ekwurzel, B. P. Schlosser, W.M. Smetthie Jr., L.N. Plummer, E. Busenberg, R.L. Michel, R. Weppernig, and M. Stute. 1994. Dating of shallow groundwater: Comparison of the transient tracers $^{3}H/^{3}He$, chlorofluorocarbons, and ^{85}Kr. Water Resource. Res. 30: 1693-1707.

Getz. 1965. Volume of Water in the Peters and Cannon Mines, Ringwood, Passaic County. June 14.

Helsel, D.R. and Hirsch, R.M. 1995. Statistical Methods in Water Resource Elsevier, 529p.

Ho, D.T., and P. Schlosser. 2000. Atmospheric SF_6 near a large urban area, Geophys. Res. Letters, 27, 1679-1682.

Hotz, P.E. 1953. Magnetite Deposits of the Sterling Lake, N.Y. – Ringwood, N.J. Area. Contributions to Economic Geology, 1952. Geological Survey Bulletin 982-F. U.S. Government Printing Office, Washington.

Kaplan, I.R., Galperin,Y., Lu, S., Lee, R. 1997. Forensic environmental geochemistry: differentiation of fuel-types, their sources and release time. Organic Geochemistry 27, pp. 289-317.

Kendall, C. and T.B. Coplen. 2001. Distribution of oxygen-18 and deuterium in river waters across the United States. *Hydrological Processes*, 15: 1363-1393.

McColloch, J.S., R.D. Binns, Jr., B.M. Blake, Jr., and G.H. McColloch, Jr., 2014. West Virginia Mine Pool Atlas Project – A Work in Progress.

Nakano, K. and Y. Shikamori. 2003. Removal of REE++ Interference on Arsenic and Selenium" in Agilent Technologies' *Agilent 8800 ICP-QQQ Application Handbook*, September.

NJDEP. 2005. Field Sampling Procedures Manual. Site Remediation Program. August.

NJDEP. 2011. Guidance for Sediment Quality Evaluations. Site Remediation Program, Bureau of Environmental Evaluation and Risk Assessment. November 1998. Updated May 3, 2011. Accessed at: http://www.nj.gov/dep/srp/guidance/sediment/

Office of the New Jersey State Climatologist at Rutgers University. 2012. Climate overview. Accessed at: http://climate.rutgers.edu/stateclim/?section=njcp&target=NJCoverview

Plummer, L.N. and E. Busenberg. 2000. Chlorofluorocarbons. *In:* Environmental Tracers in Subsurface Hydrology, Cook, P. and A.L. Herczeg (Eds.), Kluwer Academic Publishers, Boston.

Pustay, M.R. 1992. Abandoned Iron Mines of Ringwood, Wanaque, and West Milford Townships, State of New Jersey, Department of Labor, Division of Occupational Safety and Health, 61 p.

Senior, L.A. 1998. *Radon-222 in the Ground Water of Chester County, Pennsylvania*. United States Geological Survey Water-Resources Investigations Report 98-4169.

Stanford, S.D. 2002. *Surficial Geology of the Park Ridge Quadrangle, Bergen County, New Jersey*. New Jersey Geological Survey Open-File Map OFM 49.

Thomas, Robert. 2002. A Beginners Guide to ICP-MS, Part XII – A Review of Interferences, Spectroscopy 17(10), October.

USEPA. 1988a. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final. October.

USEPA. 1988b. EPA Superfund Record of Decision, Ringwood Mines/Landfill, EPA ID: NJD980529739, OU 01, Ringwood Borough, NJ. EPA/Rod/R02-88/075. September 29.

USEPA. 1989. Risk Assessment Guidance for Superfund (RAGS). Volume 1. Human Health Evaluation Manual. Part A. Interim Final. Office of Emergency and Remedial Response. December.

USEPA. 1996. Soil Screening Guidance: User's Guide. EPA/540/R-96/018.

USEPA. 1998. Standard Operating Procedure for Low-Stress (Low Flow) / Minimal Drawdown Ground-Water Sample Collection Final. March 16.

USEPA. 1999. Analytical Methods Support Document for Arsenic In Drinking Water, December.

USEPA. 2002. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. EPA/540/S-02/500, National Risk Management Research Laboratory, Office of Research and Development, Cincinnati, OH. November 2002. Accessed at www.epa.gov/swerust1/oswermna/mna_epas.htm.

USEPA. 2006a. Elizabeth Mine Superfund Site Cleanup Alternatives Fact Sheet. USEPA, Region 1, June.

USEPA. 2006b. Elizabeth Mine Protecting People, Ecosystems, and Heritage – A Shared Legacy. November.

USEPA. 2009. Letter from Joseph Gowers to Brian Bussa (Ford Motor Company) re: Modifications to the 2006 Groundwater Sampling Work Plan. May 7.

USEPA. 2011. Proposed Groundwater Sampling Modification comments.

USEPA. 2012. RadNet, Database accessed August 2012. Accessed at: http://iaspub.epa.gov/enviro/erams_query_v2.simple_query.

USGS. 2008. Hydrogeochemical Investigation of the Standard Mine Vicinity, Upper Elk Creek Basin, Colorado.

Volkert, R. 2008. *Bedrock Geologic Map of the Greenwood Lake Quadrangle, Passaic and Sussex Counties, New Jersey*. New Jersey Geological Survey Open-File Map (unpublished).

WCC. 1988. Final Remedial Investigation Report, Ringwood Mines/Landfill Site, Ringwood, New Jersey. September.

WCC. 1990. Monitoring Program Reevaluation Report, Ringwood Mines Landfill Site, Ringwood, New Jersey.

Yesenosky, S. 1965. “Junked Cars in Mine Impede Development.” Paterson Morning Call. July 21.

Zhaochu H., S. Gao, S. Hu, H. Yuan, X. Liu, and Y. Liu. 2005. Suppression of interferences for direct determination of arsenic in geological samples by ICP-MS, Journal of Analytical Atomic Spectrometry, v. 20, pp 1263-1269.